BRITISH STANDARD

BS 7159:1989

Code of practice for

Design and construction of glass reinforced plastics (GRP) piping systems for individual plants or sites

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Committees responsible for this British Standard

The preparation of this British Standard was entrusted by the Plastics Standards Policy Committee (PLM/-) to Technical Committee PLM/9, upon which the following bodies were represented:

British Board of Agrément
British Gas plc
British Plastics Federation
British Plumbing Fittings Manufacturers' Association
British Valve and Actuator Manufacturers' Association
Department of the Environment (Building Research Establishment)
Department of the Environment (Construction Industries Directorate)
Department of the Environment (Property Services Agency)
Department of Transport
Electricity Supply Industry in England and Wales
Engineering Equipment and Materials Users' Association
Health and Safety Executive
Institution of Civil Engineers
Institution of Gas Engineers
Institution of Production Engineers
Institution of Water and Environmental Management (IWEM)
National Association of Plumbing, Heating and Mechanical Services Contractors
Plastics and Rubber Institute
Plastics Land Drainage Manufacturers' Association
Royal Institute of Public Health and Hygiene
Society of British Gas Industries
Water Authorities Association
Water Companies Association
Water Research Centre

The following bodies were also represented in the drafting of the standard, through subcommittees and panels:

Association of Consulting Engineers
Department of Trade and Industry (National Engineering Laboratory)
Federation of Civil Engineering Contractors
Institution of Mechanical Engineers
Pipeline Industries Guild
RAPRA Technology Ltd.

This British Standard, having been prepared under the direction of the Plastics Standards Policy Committee, was published under the authority of the Board of BSI and comes into effect on 31 October 1989

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Contents

Foreword

This British Standard Code of practice has been prepared under the direction of the Plastics Standards Policy Committee.

It provides guidance for the design and construction of glass reinforced plastics (GRP) piping systems, within the boundaries of an individual site or adjacent sites. It thus complements codes and specifications concerned with the design and construction of a) vessels and tanks in reinforced plastics in accordance with BS 4994 and b) with the design and performance of individual pipes or fittings in accordance with BS 6464, for use as components of process plants. For the construction of GRP pipes and fittings for water supply or sewerage, attention is drawn to BS 5480 and BS 8005. For drainage, attention is drawn to BS 8301, and for pipelines of GRP, BS 8010-2.5 should be consulted.

This first edition of this British Standard has been written as a code of practice and its provisions are expressed throughout as recommendations. However, it is intended that upon review, after a period of use, a subsequent edition will emulate BS 806 and BS 4994 and take the form of a specification in which the majority of the provisions will be expressed as requirements.

The objective of this code is to ensure that the design of GRP piping systems within its scope should provide for the most severe coincident conditions of temperature, pressure and loading. It is applicable to system components of polyester, epoxy or furane resin reinforced with drawn glass in the form of chopped strand mat and/or woven roving and/or wound filaments and with or without thermoplastic liners, in nominal sizes from 25 to 1 000 in the metric series (see BS 6464). However, at this time, the detailed contents reflect the greater body of experience with inch series components in nominal sizes up to 48 (1 200) to which it is therefore also applicable. The code provides for design values for design strain to be determined in two ways: either according to the design temperature and the severity of the service environment in relation to the choice of resin, or as derived from experimental test data where the appropriate stress/environment/temperature combination can be simulated. The possible influences of corrosion and fatigue are considered and particular attention is paid to flexibility analysis.

The code includes sections on general layout, supports and anchorages and joints and concludes with guidance on quality assurance.

Additional information provided in appendices includes the following.

a) Reference to requirements applicable to plastics pipework components likely to come into contact with potable water.

b) Methods of test for determination of the effects of relevant liquid environments, on resistance to long term hydrostatic pressure or to fatigue, which provide factors to be taken into account for purposes of stress analysis.

c) Guidance on accommodation of pipework expansion and contraction.

d) Nominal dimensions of lengths and radii to be assumed or specified for fittings to enable the initial planning of pipework layouts.

e) General guidance on non-destructive testing.

f) Recommendations for procedure approval testing.

g) Descriptions of various irregularities in pipe or fitting construction together with a classification of their respective significance and recommended remedial procedure.

h) Recommended stages of inspection for quality assurance purposes.

j) A bibliography of related publications.

In selecting the symbols and units adopted for this standard, particular account has been taken of those established for use in respect of the specification and design of GRP pipes, fittings and vessels, primarily in BS 6464 and BS 4994 and, for similar design purposes, for ferrous piping installations in BS 806. For some purposes, these complementary standards have selected differing conventions or options from one another. Hence, to avoid assigning a multiplicity of meanings to the use of any individual symbols within this standard, it has been necessary to use for some parameters an alternative symbol or unit to that which may be found in a complementary or analogous standard.

It has been assumed in the drafting of this standard that the design of GRP piping systems is entrusted to qualified engineers and that the execution of their construction is carried out under the direction of appropriately qualified supervisors.

WARNING NOTE. This code does not necessarily detail all precautions necessary to meet the requirements of the Health and Safety at Work etc. Act 1974. Attention should be paid to any appropriate regulations and safety precautions, for example concerning the execution of installations on site, and the procedures and test methods described should be operated only by trained personnel.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i to vi, pages 1 to 80, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

Section 1. General

1.1 Scope

This code of practice gives recommendations for the design, fabrication, installation, testing and inspection of glass reinforced plastics (GRP) piping systems, with or without thermoplastics linings, within the boundaries of individual or associated sites for general chemical engineering purposes such as chemical plants, process plants, refineries, steam-raising units, storage and distribution depots and tank farms.

It is particularly applicable to systems based on use of pipes having an internal diameter of 25 mm to 1 200 mm or equivalent (nominal sizes 25 to 1 200) and intended for use in the temperature range of – 30 °C to + 110 °C and/or internal pressures of up to 10 bar in the case of pipes up to 600 mm internal diameter or up to 6 bar in the case of pipes having internal diameters greater than 600 mm.

This code does not include recommendations specific to the particular needs of cross-country pipelines outside the boundaries already described or of underground or under-water effluent or drainage systems, although general aspects of its guidance may be helpful where not in conflict with other codes of practice for such purposes.

Additional information or guidance is provided in appendices concerning requirements for non-metallic materials for use in contact with potable water, determination of design strain, flexibility and stress analyses, design details of fittings, non-destructive testing, procedural approval, inspection and repair procedures.

NOTE The titles of BSI publications referred to in this standard are listed on page 80. References to publications (other than BSI publications) are identified in the text by numbers in square brackets and are listed in Appendix J.

1.2 Definitions

For the purposes of this code the definitions given in BS 1755-1 apply, together with the following.

1.2.1
C glass

an alkali calcium glass with an enhanced boron trioxide content and intended for applications requiring enhanced chemical resistance accordingly

NOTE This definition is consistent with ISO 2078:1985 and equivalent to DIN 1259-1:1986.

1.2.2
curing

the chemical reaction resulting in the final polymerized product

NOTE It may be effected at ambient temperature or by the use of heat. In certain resin systems the cure has to be effected in two stages: the first stage, may, and the second stage does, involve the application of heat. This second stage is known as the "post-cure".

1.2.3
design temperature

the maximum fluid temperature for each design condition that can be reached during that operating condition

1.2.4
design pressure, p_d

the internal pressure to be used in calculations to establish the required strength of the component part (see **5.2**)

1.2.5
laminate[1)]

a resin reinforced with a form of glass fibre material

1.2.6
nominal size

a numerical designation of size which is common to all components in a piping system other than components designated by outside diameters or by thread size. It is a convenient round number for reference purposes and is only loosely related to manufacturing dimensions

NOTE 1 For some pipe systems, nominal sizes are designated by DN followed by a number.
NOTE 2 The nominal size (DN) cannot be subject to measurement and therefore is not suitable for purposes of calculation.
NOTE 3 Not all piping components are designated by nominal size: for example thermoplastics pipes designated in accordance with ISO 161-1 are sized in respect of their external diameter.

1.3 Abbreviations

The following abbreviations are used in two or more sections and/or appendices.

CF	continuous filaments
CSM	chopped strand mat
GRP	glass reinforced plastics
NDT	non-destructive testing
p.c.d.	pitch circle diameter
SIF	stress intensification factor
WR	woven roving

[1)] Definition differs from that given in BS 1755-1, for consistency with BS 4994 and BS 6464.

NOTE For reference to materials in pipework components made of unplasticized polyvinyl chloride, use is made in this standard of both "PVC" and "PVC-U". The former is used in contexts where its use may still be found through reference to current editions of standards such as BS 3506, BS 3757 and BS 4346. The latter is used in references of a general nature, or to BS 3505, where its use is becoming established and is consistent with the choice of symbols for recent standards published by the International Organization for Standardization (ISO) for pipes or fittings of such materials.
The symbol "uPVC", which may be found in some trade literature and general purpose codes of practice, is not used in this standard, because it is not in accordance with BS 1755-1:1982 or ISO 1043-1:1987.

1.4 Symbols

For the purposes of this code, the following symbols apply.

A	length of a flange or stub flange
A_σ	stress range during a fatigue cycle
b	coefficient for linear regression line
B	length of one leg of a 90° bend
c	constant for a linear regression line
C	length of one leg of a bend of other than 90°
d	internal diameter of the small end of a reducer
D	internal diameter of the large end of a reducer
D_i	internal diameter of a pipe or fitting
D_{iB}	internal diameter of the branch of a tee
$D_{iB\,1}$ } $D_{iB\,2}$	internal diameters of adjacent branches on a pipework system (see Figure D.1 and Figure D.2)
D_{iM}	internal diameter of the main of a tee
D_{na}	diameter of the neutral axis of a stiffening ring on a pipe
D_o	outside diameter of pipe
D'	outside diameter of a stub flange
E	modulus of elasticity of a (flange) material
E_{LAM}	modulus of elasticity of a laminate
$E_{LAM\,x}$	modulus of elasticity of a reference laminate in the longitudinal direction
$E_{LAM\phi}$	modulus of elasticity of a reference laminate in the circumferential direction
E_2	distance from the axis of the branch of a flanged tee to the end of the main
E_3	distance from the mouth of the branch of a flanged tee to the bore of the main
f_N	anchor load
F_s	factor of safety
G	length of the end of a reducer
h	internal diameter of a loose backing flange
H	external diameter of a loose backing flange
I	second axial moment of area (about an axis through the centroid normal to the axis of the pipe)
J	distance between stiffening rings on a pipe
$J_{B\,1}$ } $J_{B\,2}$	spacing between adjacent branches on a pipe-work system applicable to the internal diameter of the respective branches
J_s	length of a (straight) shell contributing to the effect of a stiffening ring
k	factor to compensate for the thermal effects of process gases or liquids respectively
K_n	fatigue factor
L	span (of supported pipework) [also used as a prefix for reference laminate numbers — see Table 5.1]
L_B	length of overlay along a branch
L_{OVL}	length of overlay (for a joint)
L_2	socket depth (for a cemented joint) (for a pressure application)
m	pressure stress multiplier
M	applied bending moment (for testing prototype flange designs)
M_i	maximum in-plane bending moment (on a bend)
M_o	maximum out-of-plane bending moment (on a bend)
M_S	torsional moment
n	number of stress cycles during design life
n_f	number of fatigue test cycles to failure
n_x	number of layers of glass fibre of type x (in a laminate)
N	thickness of a stub flange
p	internal pressure (gauge)
p_d	design pressure (internal) (gauge)
p_e	allowable external pressure (gauge)
p_{95}	95 % lower confidence limit of the internal pressure to produce pipe failure after the design life
P	point load (along a span of supported pipework)
$Q_{C\,max}$	maximum compressive unit loading

r	radius of pipe or fitting bore
R	mean radius of a pipe bend
R'	root radius of a flange
S_B	length of a branch end from the main pipe bore
S_M	length of a main pipe end from a branch pipe bore
S_s	lap shear strength
SIF_b	stress intensification factor for a bend
SIF_{Bi}	in-plane branch stress intensification factor
SIF_{Bo}	out-of-plane branch stress intensification factor
SIF_T	stress intensification factor for a tee
SIF_{xi}	longitudinal SIF under in-plane bending
SIF_{xo}	longitudinal SIF under out-of-plane bending
$SIF_{\phi i}$	circumferential SIF under in-plane bending
$SIF_{\phi o}$	circumferential SIF under out-of-plane bending
t	thickness of the laminate
t_d	design thickness of the reference laminate
t'	thickness of a backing flange
t_B	thickness of the wall of the branch on a tee, adjacent to the main
t_{CSM}	thickness of a (model) pipe of CSM construction
t_M	thickness of the reference laminate(s) of the main of a tee
T_a	ambient temperature
T_p	process temperature
ΔT_d	design temperature change
ΔT_e	equivalent temperature change
u	ultimate tensile unit strength
u_x	ultimate tensile unit strength in the longitudinal direction
u_ϕ	ultimate tensile unit strength in the circumferential direction
W	distributed load (along supported pipework)
W_x	mass of glass reinforcement per unit area of one layer of type "x"
W_w	wind loading (distributed, along exposed pipework)
x	variable alphanumeric character, e.g. "glass reinforcement type x" where x can be replaced by a specific numeral or character to identify the particular type
X_x	unit modulus of glass reinforcement type "x"
X_{LAM}	laminate unit modulus
$X_{LAM\ d}$	design laminate unit modulus
$X_{LAM\ x}$	laminate unit modulus in the longitudinal direction
$X_{LAM\ \phi}$	laminate unit modulus in the circumferential direction
y_1	power for the pipe factor of a bend as a function of flexibility factor
y_2	power for the pipe factor of a bend as a function of stress intensification factor
y_3	power for the pipe factor of a tee as a function of stress intensification factor
y_4	power for the pipe factor of a tee as a function of pressure stress multiplier
α_ℓ	linear thermal expansion coefficient
α_1	coefficient for the pipe factor of a bend as a function of flexibility factor
α_2	coefficient for the pipe factor of a bend as a function of stress intensification factor
α_3	coefficient for the pipe factor of a tee as a function of stress intensification factor
α_4	coefficient for the pipe factor of a tee as a function of pressure stress multiplier
β	function of α_ℓ to relate pressure induced strain to thermally induced strain
γ	correction factor for the effect of internal pressure on flexibility factor
δ_x	correction factor for the effect of internal pressure on longitudinal SIF
δ_ϕ	correction factor for the effect of internal pressure on circumferential SIF
Δ	incremental change in a quantity (e.g. ΔT — see **7.2.2**)
ϵ_d	design strain
ϵ_r	resin fracture strain
$\epsilon_{x\ p}$	longitudinal strain induced by internal pressure
$\epsilon_{(10\ E\ 7)}$	predicted strain to cause failure after 10^7 cycles (of a tensile fatigue test)
ϵ_ϕ	circumferential strain

θ	winding angle, relative to the longitudinal axis of filament winding
κ	flexibility factor
κ_b	flexibility factor of a bend
κ_i	in-plane flexibility factor of a bend
κ_o	out-of-plane flexibility factor of a bend
κ_s	flexibility factor of a straight of composite construction, e.g. CSM + WR
$\kappa_{s\,CSM}$	flexibility factor of a straight CSM pipe of matching $X_{LAM\,d}$ to a pipe of composite construction
λ	pipe factor
λ_b	pipe factor of a bend
λ_T	pipe factor of a tee
λ_Z	pipe factor of a pressurized tee
ν	the Poisson ratio
$\nu_{x\phi}$	the Poisson ratio, giving strain in the circumferential direction caused by stress in the axial direction
$\nu_{\phi x}$	the Poisson ratio, giving strain in the axial direction caused by stress in the circumferential direction
ν_{12}	the Poisson ratio, giving strain in direction 2 caused by stress in direction 1
ν_{21}	the Poisson ratio, giving strain in direction 1 caused by stress in direction 2
σ_{bB}	non-directional bending stress at a branch
σ_c	combined stress
σ_{cB}	branch combined stress
σ_{Cd}	design compressive stress
σ_d	design stress
$\sigma_{max\,b}$	maximum stress in a bend in flexure
$\sigma_{max\,f}$	maximum stress in a fatigue test
$\sigma_{max\,s}$	maximum stress in a straight pipe in flexure
σ_n	maximum stress during a fatigue cycle
σ_S	torsional stress
σ_{SB}	branch torsional stress
σ_x	longitudinal stress
σ_{xb}	longitudinal bending stress
σ_{xp}	longitudinal pressure stress
$\sigma\phi$	circumferential stress
$\sigma\phi_b$	circumferential bending stress
$\sigma\phi_p$	circumferential stress induced by internal pressure at a tee
$\sigma_{(10\,E\,7)}$	estimated stress that would cause failure in 10^7 cycles during fatigue testing

1.5 Information and requirements to be agreed and documented

1.5.1 Information to be supplied by the purchaser

The following information should be supplied by the purchaser and should be fully documented. Both the recommendations provided throughout the standard and the documented items should be satisfied before a claim of compliance with this standard can be made and verified.

a) Process conditions.

1) Materials to be handled (names, concentrations and relative densities) including likely impurities or contaminants.

2) Design pressure (or vacuum) including test requirements and design temperature.

3) Operating pressure (or vacuum) and temperature.

4) Mode of operation, e.g. process cycling conditions.

5) Any abrasion or erosion problems which may be encountered.

b) Site conditions.

1) Nature of ambient atmosphere including any extremes of temperature.

2) Superimposed loads, e.g. wind, snow and associated pipework.

3) Loads imposed by personnel during erection and operation.

4) Seismic loading.

c) Details of any special or additional tests or inspection required and where these are to be carried out (see **11.1** and **11.12**).

d) Requirements for testing (see section 11).

e) Name of Inspecting Authority, if applicable.

f) Requirements for packaging, despatch and installation.

g) Flange standard and rating (see **10.6**).

1.5.2 Requirements to be agreed and documented

The following items to be agreed between the purchaser (or the Inspecting Authority, where appropriate) and the manufacturer should be fully documented. Both the recommendations provided throughout the standard and the documented items should be satisfied before a claim of compliance with this standard can be made and verified.

a) Resin system to be used (see **3.1**).

b) Type of chemical barrier to be used, thermoplastic or thermosetting, and any additional corrosion barrier (see **4.2.2.5**).

c) Design details (see section 2).

1) Essential dimensions, including tolerances, preferably on a drawing.

2) Design calculations with references.

3) Nominal thickness, including tolerance, of corrosion-resistant lining (thermoplastics or gel coat) which does not contribute to strength (see **3.5** and **4.2.2.5**).

4) Form(s) of reinforcement including type, number and arrangement of individual layers (see **5.3**).

5) Form(s) of local stiffening, where used (see **6.3**).

6) Details of thermoplastics linings (see **11.6.1**).

7) Gasket materials and details.

d) Where the design incorporates reinforcement with directional properties, the orientation of the fibres (see **4.2.2.3**).

e) Supports (see **7.4** and section 9).

f) Any modification to the approved design.

g) Where site fabrication is employed, the special procedures to be adopted (see **10.1.6**, **11.3** and **11.4**).

h) Repair of laminate defects and method of repair (see **11.8** and Appendix G).

i) Whether an alternative welding method is to be used (see **11.6.3**).

j) The provision of special test laminates and the extent of the mechanical testing to be carried out either on cut-outs or prepared laminates (see **11.5**).

k) If the prototype tests are not to be witnessed by the purchaser, and the Inspecting Authority, where applicable (see **10.1.7**).

l) The nature of prototype tests, the hydraulic test pressure if it is higher than the design pressure and the limits of cyclic variations to determine fatigue strength (see **10.6** and **4.3.4**).

Section 2. Design objectives and general recommendations

2.1 Basis of design

2.1.1 Aim of design

The aim of design is the achievement of an acceptable probability that systems being designed will perform satisfactorily during their intended life. With an appropriate degree of safety, the system should sustain all the stresses and deformations of normal construction and use.

2.1.2 Design procedure

The design of GRP piping systems should provide for the most severe coincident condition of temperature, pressure and loading. Where two or more distinct conditions occur they should be separately evaluated using the applicable design pressure, design temperature and loadings in each case considered. It is essential to consider that the most severe conditions for pressure containment design may not be the same as the most severe conditions for flexibility analysis.

A flow chart to summarize the design procedure envisaged by the code is given in Figure 2.1 and includes references to the supporting sections of this code as appropriate.

2.2 Sizes, dimensions and tolerances

2.2.1 Nominal sizes and diameters

Both nominal and actual pipe sizes and/or diameters may be selected to match those of an established product specification, for compatibility of jointing and marking. Unless otherwise thus specified, the nominal size of pipes and associated fittings should be in accordance with a), b) or c) as applicable.

For the purposes of this standard, nominal sizes in accordance with a) have been assumed to be indicative of the internal diameter of the pipe, in particular in respect of the purposes of **5.4** and Table 5.2 to Table 5.5 inclusive, **10.4** and Table 10.3 to Table 10.7 inclusive and for Appendix D.

a) *Unlined pipe systems*. The nominal size of pipes and fittings should be one of the following values:

40 50 80 100 150 200 250 300 350
400 450 500 550 600 650 700 750
800 850 900 950 1 000 1 050 1 100
1 150 1 200

The manufacturer should declare the actual internal diameter (in mm) of the pipes and fittings related to the relevant nominal size.

b) *Lined pipe systems using extruded pipe and moulded fittings*. The nominal size of the pipe should be based on the nominal size of the extruded pipe (see **3.5**).

NOTE Account should be taken, on sizing of the system, of any consequential reduction of the bore size below that of unlined pipe.

c) *Lined pipe systems using fabricated linings*. The nominal size of pipe and fittings should be one of the sizes listed in a).

2.2.2 Other diameters

Limiting values for selected dimensions are recommended for joints, including differences between bores (see **10.1.4**), overlay lengths (see **10.1.5**), socket dimensions (see **10.4**) and thermoplastics linings (see **11.6**).

Nominal values for selected dimensional design details of GRP fittings are given, to assist joint layout (see **8.2** and Appendix D).

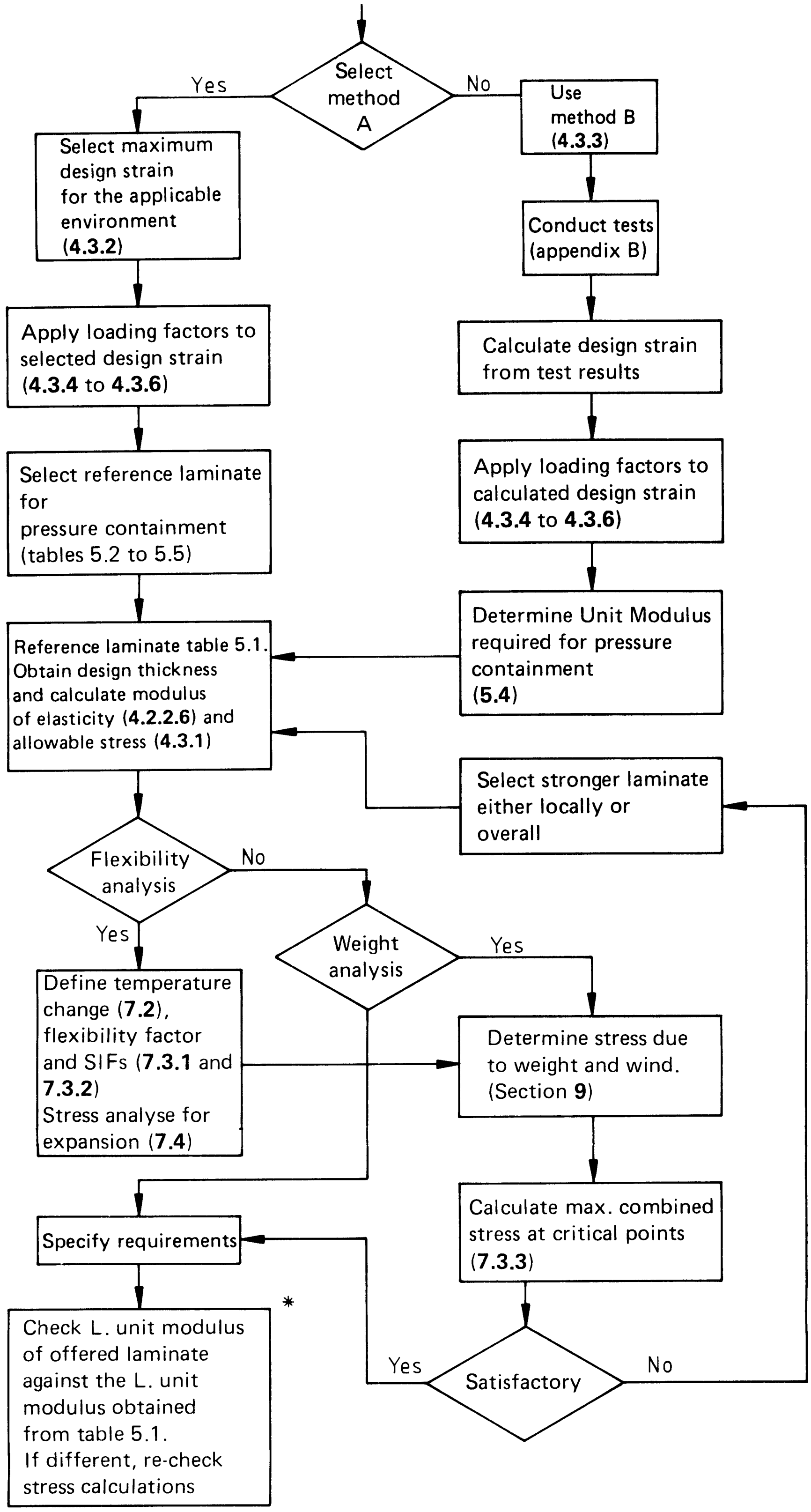
2.2.3 Tolerances

The following tolerances should be applied.

a) *Pipes and fittings*. Tolerances on dimensions of pipes and fittings of GRP should be in accordance with **19.1** of BS 6464:1984.

b) *Flanges*. Manufacturing tolerances on flanges should be in accordance with **26.4.4.2** of BS 6464:1984.

c) *Reference laminates*. Manufacturing tolerances for reference laminates in the form of straight pipes are given in Table 5.6.



* "L" represents "Laminate".

Figure 2.1 — Flow chart of design procedure

Section 3. Materials

3.1 Thermosetting resin systems

The thermosetting resins used for the manufacture of pipes and fittings may be of a number of types. There are many resin systems in each type and the properties of these systems vary, especially with respect to chemical resistance and temperature of deflection [heat distortion temperature (see **4.4**)].

Resin systems should comply with a relevant British Standard, as applicable. Thus, for example, polyester resin systems should comply with the requirements of BS 3532.

In order for the chemical reaction to take place, resulting in the final polymerized product, hardeners, catalysts and accelerators should be added to the resin in accordance with the manufacturer's recommendations.

The amount of hardener, catalyst and/or accelerator used should be regarded as critical, as it can affect both the rate of reaction and extent of the cure.

It is recommended that the temperature of deflection of the resin (see **4.4**), when measured in accordance with BS 2782:Method 121A and using resin cured according to a schedule representative of that used for the finished pipework, should in all cases be at least 20 °C higher than the design temperature (see **1.2.3**).

If required, the resin to be used for the outer layers of the pipe or fitting may incorporate pigments, dyes or specific ultraviolet light absorbers to prevent the transmission of UV light and/or for identification purposes.

3.2 Fibrous reinforcement

Except for alternative surface tissues (see **3.3**) all fibrous reinforcement should be derived from continuously drawn filaments of "E" glass (1146)[2] (see note) and used in the following forms alone or in any combination subject to compatibility with the resin system used.

a) Chopped strand mat in accordance with BS 3496.

b) Woven fabric in accordance with BS 3396-1, BS 3396-2 or BS 3396-3 as applicable.

c) Woven fabric in accordance with BS 3749.

d) Rovings in accordance with BS 3691.

NOTE Such glass includes either alumino-borosilicate glass or alumino-calco-silicate glass, in either case optionally containing other oxides, mainly aluminium trioxide, incorporated for enhanced corrosion resistance and then sometimes described as E.CR glass.

3.3 Surface tissues

Tissues optionally incorporated into the superficial layers of the internal and/or external surfaces of a GRP pipe or fitting should be made from one or more of the following:

a) glass materials in accordance with **3.2**;

b) C glass (see **1.2.1**);

c) woven or non-woven textiles based on polyester or acrylic fibres.

3.4 Aggregates and fillers

The resin used should contain only fillers as required for viscosity control; they should be limited to a maximum of 5 % of the mass of the resin and should not interfere with the capability to visually inspect the laminate.

Special additives, such as aggregates, graphite and fire retardants, etc., should only be used to impart special properties, e.g. stiffness, conductivity.

3.5 Thermoplastics liners

If thermoplastics liners are used, the materials should be selected on the basis of resistance to the fluid to be carried.

If unplasticized polyvinyl chloride (PVC-U) is the specified liner material, PVC pipe complying with BS 3505 or BS 3506 should be used. For pipes of nominal sizes up to 500 (metric series) the grade of material used should be suitable for the manufacture of pipe in accordance with BS 3505 or BS 3506, depending upon the need to satisfy the requirements of **3.7**. For nominal sizes greater than 500 unplasticized PVC sheet complying with BS 3757, and as necessary **3.7** of this standard, should be used for fabrication (see **11.6**).

Recommended limits for the thickness of liners are given in **11.6.1**.

General guidance on the fabrication and assembly of thermoplastics liners is given in section eleven, including recommendations in **11.6** and **11.7** for the preparation and testing of welded joints.

Specialized liners made of materials such as chlorinated polyvinyl chloride (PVC-C), FEP, PVDF, PTFE, PCTFE [poly (chlorotrifluoroethylene)] and ethylene-chlorotrifluoroethylene copolymer (ECTFE) may be required for very difficult conditions.

[2] Term no. in accordance with BS 3447:1962.

3.6 Cement for bonding spigot and socket joints

It may be necessary to ensure that the bonding cement will be satisfactory for the chemical conditions specified, and to take account of the cement manufacturer's recommended limits for the ambient conditions required for the bonding system to cure properly.

NOTE Recommended limits for cemented socket and spigot joints are given in **10.4**.

3.7 Non-metallic materials for potable water applications

If the system is intended for use in contact with potable water, it is essential that the requirements detailed in Appendix A are incorporated into the specifications for the materials when in the form of the system components, e.g. pipes, fittings, cemented joints, linings.

The marking requirements in specifications for such pipes and fittings should be consistent with the corresponding requirements of BS 5480-1 (the letter "P" set in a box thus [P]).

Section 4. Mechanical properties and design stress or design strain

4.1 General

This section gives preferred design values for mechanical properties. It also gives design values for design strain according to design temperature and degree of severity of service environment in relation to choice of resin. As an alternative and where deemed appropriate, design strain may be derived from experimental test data on pipes or laminates under stress in the chemical environment and at the design temperature. The latter approach is likely to produce a higher design strain than that defined in the absence of test data; it will therefore be attractive for high-cost contracts, or for recurrent material/environment/temperature combinations.

Allowable design strain should take into account fatigue loadings using the method given in **4.3.4**.

A restriction on design strain applicable when using resins with low fracture strain is detailed in **4.3.5**.

Derivation of design values for mechanical properties of filament-wound pipe is given in **4.2.2** and restrictions on design strain for such pipe in **4.3.6**.

The use of additional glass layers as a corrosion barrier and its significance in pipe design calculations is described in **4.2.2.5**.

NOTE Attention is drawn to a general recommendation in respect of the temperature of deflection of the resin in **3.1**.

4.2 Mechanical properties

NOTE Where applicable, it is considered desirable to work in terms of unit load (i.e. force per unit width per unit mass of glass) rather than stresses (i.e. force per unit area).

4.2.1 Laminate layers

Table 4.1 gives design values for mechanical properties of laminate layers for use in the manufacture of pipe and fittings. These values are also recommended as the minimum acceptable properties for laminate layers of manufactured pipework.

Table 4.2 — Types of laminate construction

Type of laminate	Form of construction
Type 1	All chopped strand mat (CSM) construction with an internal and an external surface tissue reinforced layer
Type 2	Chopped strand mat (CSM) and woven roving (WR) construction with an internal and an external surface tissue reinforced layer
Type 3	Chopped strand mat (CSM) and multi-filament roving construction with an internal and an external surface tissue reinforced layer

Table 4.1 — Mechanical properties of laminate layers

Type of resin	Type of glass reinforcement	Ultimate tensile unit strength (u)	Unit modulus (X)	Lap shear strength (S_s)
		Method of test		
		B.3 of BS 6464:1984	B.4 of BS 6464:1984	B.5 of BS 6464:1984
		N/mm width (per kg/m^2 glass)	N/mm width (per kg/m^2 glass)	
Polyester and epoxide	Chopped strand mat	200	14 000	7.0
	Woven rovings	250	16 000	6.0
	Unidirectional woven rovings	450	25 000	6.0
	Continuous rovings	500	28 000	6.0
Furane	Chopped strand mat	140	14 000	5.0
	Woven rovings	160	16 000	4.0
	Unidirectional woven rovings	250	25 000	3.5
	Continuous rovings	280	28 000	3.5

4.2.2 Laminates

4.2.2.1 *Types of laminates*. For the purposes of this standard, it is convenient to classify the construction of laminates into three types as described in Table 4.2.

4.2.2.2 *Design values for modulus and thickness*. Design values for type 1 and type 2 laminates and for type 3 laminates with a winding angle of ± 55° are given in Table 5.1 for the following parameters:

a) laminate unit modulus;

b) design thickness.

Values for the design modulus of elasticity of the laminate, E_{LAM}, can be obtained using equation (4.2) [see **4.2.2.6** c)].

4.2.2.3 *Design unit modulus for filament wound pipes*. If continuous rovings are filament wound at an angle of $\pm \theta$ to the pipe axis, values of circumferential and longitudinal unit modulus should be taken from Figure 4.1.

Design calculations should take account of the anisotropic stiffness of filament wound pipes and the complex strain response and should analyse for the maximum principal strain. For such purposes, attention is drawn to **9.2.7** of BS 4994:1987.

4.2.2.4 *Design values for the Poisson ratio* ν. Design values applicable for the Poisson ratio are dependent upon the type of laminate: thus for type 1 and type 2 laminates a design value of 0.3 is recommended whereas for type 3 laminates the design value should be selected as a function of the direction of stress and the angle of winding as shown in Figure 4.2.

4.2.2.5 *Additional corrosion barrier*. Additional layers of glass reinforcement may be specified by the purchaser or manufacturer to take account of chemical degradation and/or erosion. Any such layers should be taken into account when determining thermal expansion end loads and in flexibility analysis (see section 7) but not in any other design calculation.

4.2.2.6 *Laminate values*. Mechanical property values for specific pipe and fitting wall laminates should be calculated from the values given in Table 4.1, and the selected masses of glass reinforcement to be used in the wall laminates as follows for manufactured pipework (see **4.2.2.5**).

a) *Laminate unit modulus*. The unit modulus of the wall laminate can be calculated from the following equation:

$$X_{LAM} = n_1 W_1 X_1 + n_2 W_2 X_2 + \ldots n_x W_x X_x \qquad (4.1)$$

where

X_{LAM} is the laminate unit modulus (in N/mm);

n_x is the number of layers of glass reinforcement of type x;

X_x is the unit modulus of glass reinforcement type x [in N/mm width (per kg/m^2 glass)];

W_x is the mass of glass reinforcement per unit area (in kg/m^2) in one layer of type x.

b) *Laminate thickness*. The laminate thickness is dependent on the type of glass reinforcement and resin used. The manufacturer should state the thickness of the laminate being offered.

c) *Laminate modulus*. The modulus of elasticity for the laminate is obtained from the following equation:

$$E_{LAM} = \frac{X_{LAM}}{t_d} \qquad (4.2)$$

where

E_{LAM} is the modulus of elasticity of the laminate (in MPa);

X_{LAM} is the laminate unit modulus (in N/mm);

t_d is the design thickness of the reference laminate (in mm) excluding any corrosion barrier (see **4.2.2.5**).

4.3 Design stress and design strain

4.3.1 Determination

Design strain should be determined as described in **4.3.2** or **4.3.3**.

Design stress and design strain are related through the modulus of elasticity of the laminate thus:

$$\sigma_d = \epsilon_d E_{LAM} \qquad (4.3)$$

where

σ_d is the design stress (in MPa);

ϵ_d is the design strain;

E_{LAM} is the modulus of elasticity of the laminate (in MPa).

NOTE Design strain is the short-term value of allowable strain. Because of the effects of creep, strain will increase with time. It may sometimes be necessary to take this into account using an appropriate value of creep modulus, e.g. where long-term pipe deflection is critical. In general the effects of creep are small and may be neglected.

4.3.2 Method A. Use of defined design strain values

4.3.2.1 *Design strain classification system*. In this approach values of design strain are restricted to those given in Table 4.3 and classified accordingly.

4.3.2.2 *Selection of design strain value*. Table 4.4 expresses recommended strain class ratings, and hence allowable design strain values, in terms of temperature (see **4.3.2.3**) and chemical environment classifications (see **4.3.2.4**) appropriate to the chosen pipe wall material.

The values given in Table 4.3 are applicable to low fatigue conditions (less than 1 000 cycles); otherwise they should be modified according to **4.3.4**. The design strain limitations of **4.3.5** and **4.3.6** should also be imposed when applicable.

Table 4.3 — Strain class ratings

Class	Design strain
Class 1	0.0018
Class 2	0.0015
Class 3	0.0012
Class 4	0.0009

Table 4.4 — Application of strain classifications to environmental conditions

Chemical conditions (see **4.3.2.4**)	Temperature conditions (see **4.3.2.3**)	
	NORMAL	HIGH
MILD	Class 1	Class 2
SEVERE	Class 3	Class 4

4.3.2.3 *Temperature classifications*. The classification of "NORMAL" or "HIGH" temperature used in Table 4.4 depends on the relationship of each design temperature (see **1.2.3**) to the temperature of deflection of the resin when measured in accordance with BS 2782:Method 121A with the resin cured to a schedule representative of that to be applied to the finished pipework.

The criteria used are as follows.

a) NORMAL temperature: the design temperature should be at least 40 °C below the temperature of deflection of the chosen resin (see **4.4**).

b) HIGH temperature: the design temperature should be at least 20 °C below but not more than 40 °C below the temperature of deflection of the chosen resin (see **4.4**).

4.3.2.4 *Classification of chemical conditions*. The classification of "MILD" or "SEVERE" chemical conditions used in Table 4.4 depends on the loss in flexural strength caused by the chemical environment when unstressed laminate specimens as near as possible to but not exceeding 6 mm in thickness, and subjected to a cure schedule simulating that to be used for the finished pipework, are totally immersed for a minimum of 6 months at the design temperature.

a) MILD chemical conditions: this condition applies when the loss in flexural strength is less than 20 % of the original value when measured in accordance with BS 2782:Method 1005.

b) SEVERE chemical conditions: this condition applies when the loss in flexural strength is more than 20 % but less than 50 % of the original value when measured in accordance with BS 2782:Method 1005.

If the loss of flexural strength is greater than 50 % of the original value, then the matrix fibre system should be deemed unsuitable and not used, except with an appropriate thermoplastic liner (see **4.3.2.6**).

The strength loss data from which a chemical classification can be made will generally be available from the resin manufacturer.

4.3.2.5 *Design strain loading factors*. When values of design strain taken from Table 4.3 are modified according to **4.3.4**, **4.3.5** or **4.3.6**, the design strain adopted should be that from Table 4.3 which is closest to, but not greater than, the derived value. If the derived value is less than 0.0009 then the strain class rating concerned should be deemed unsuitable for the proposed service.

4.3.2.6 *Use of a thermoplastics liner*. When a thermoplastics liner is used throughout a pipe system, MILD chemical conditions should be assumed when selecting a design strain from Table 4.3. Design strain loading factors taken from **4.3.4**, **4.3.5** and **4.3.6** should then be applied.

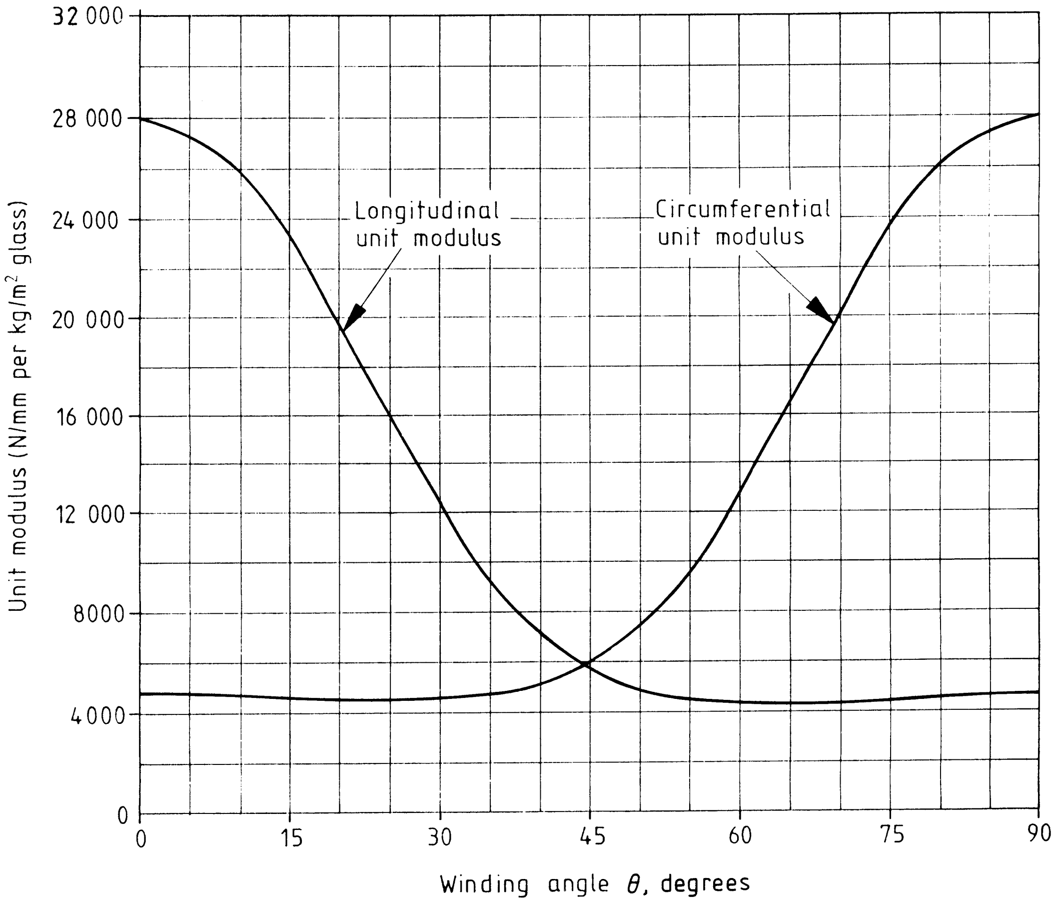
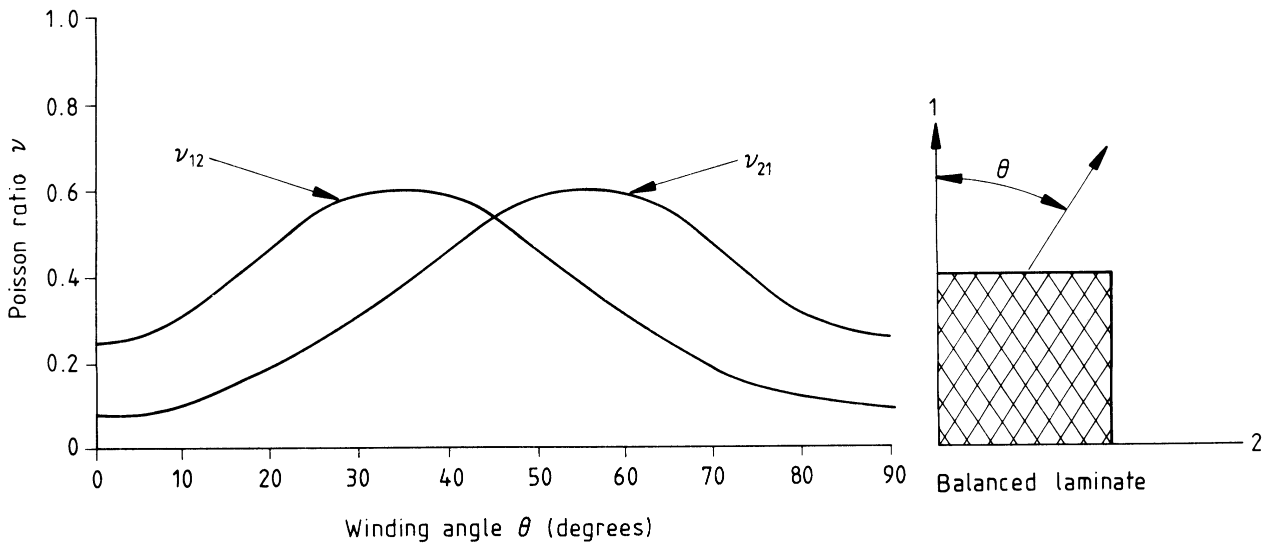


Figure 4.1 — Unit modulus/winding angle



NOTE ν_{12} is the Poisson ratio giving strain in direction 2 caused by stress in direction 1; ν_{21} is the Poisson ratio giving strain in direction 1 caused by stress in direction 2; θ is the winding angle relative to the longitudinal axis.

Figure 4.2 — Variation of the Poisson ratio with winding angle for filament-wound pipe

4.3.3 Method B. Derivation of design strain from mechanical test data

As an alternative to the approach of **4.3.2**, a maximum design strain may be derived from mechanical test data pertaining to stressed specimens exposed to the process fluid at the design temperature. Details of experimental methods are given in Appendix B. Values of design strain so determined should be modified, as necessary, in accordance with **4.3.4**, **4.3.5** and **4.3.6**.

Design strains obtained by this method could be significantly higher than those obtained by method A (**4.3.2**).

4.3.4 Design for fatigue

In cases where design loadings incorporate a significant cyclic or fluctuating stress component, design strains should be downrated by dividing by a fatigue factor, K_n, derived from equation (4.4).

This equation links the fatigue factor to the expected magnitude of stress variations so that low stress range variations are given less significance than high stress range variations.

Fatigue loadings should be discounted for less than 1 000 cycles, or if the stress range of stress cycles is less than 0.2 (20 %) of the design stress.

$$K_n = 1 + 0.25(A_\sigma/\sigma_n)\ (\mathrm{Log}_{10}(n) - 3) \qquad (4.4)$$

where

K_n is the fatigue factor;

n is the number of stress cycles during design life;

A_σ is the stress range during a fatigue cycle (in MPa);

σ_n is the maximum stress during a fatigue cycle (in MPa).

Example: For 3×10^6 cycles with a magnitude of 4 MPa and a design stress of 10 MPa,

$$K_n = 1 + 0.25(4/10)\ (6.477 - 3) = 1.35$$

A convenient means for determining the change in strain class ratings as a function of fatigue conditions in service for systems designed using method A is provided as Figure 4.3. The maximum possible increase in strain class ratings is 3, i.e. from class 1 (design strain = 0.0018) to class 4 (design strain = 0.0009) (see Table 4.3). Within a given zone, the resulting design is pessimistic. If the conditions would require a strain class rating to be greater than class 4 (design strain = 0.0009), it is not possible to use method A as the basis for the design.

4.3.5 Design strain limitations for low fracture strain resins

When a resin of low fracture strain (less than 0.02) is used, the laminate design strain, ϵ_d, should satisfy the relationship in the following expression:

$$\epsilon_d \leqslant 0.1\ \epsilon_r \qquad (4.5)$$

where

ϵ_r is the resin fracture strain.

4.3.6 Design strain limitations for filament wound pipes

For pipes manufactured using continuous rovings filament wound at any angle between ± 15° and ± 75° to the pipe axis, a rigorous anisotropic elastic analysis should be carried out to confirm that the design strain derived as in **4.3.2** or **4.3.3** is not exceeded under design conditions. The analysis should allow for the interaction between normal and shear strain. Without such an analysis the design strain adopted should be no greater than 0.0009.

When continuous rovings are filament wound at any angle less than 15° to the pipe axis, the circumferential unit modulus of such rovings should not be taken into account in determining the value of E_{LAM} for calculating the design stress (see **4.3.1**).

When continuous rovings are filament wound at any angle greater than 75° to the pipe axis, the longitudinal unit modulus of such rovings should not be taken into account in determining the value of E_{LAM} for calculating the design stress (see **4.3.1**).

4.4 Temperature of deflection

NOTE The term "heat distortion temperature" and the abbreviation "HDT" have been used previously, in particular by BS 6464:1984 and BS 4994:1987, to describe the property measured by the method described in BS 2782:Method 121A but the term "temperature of deflection" is currently used for this property by this test method and by BS 3532.

When required the temperature of deflection of the resin when measured in accordance with BS 2782:Method 121A, should in all cases be at least 20 °C higher than the design temperature (see **4.3.2.3**) using the resin cured according to the schedule representative of that to be used for the finished pipework.

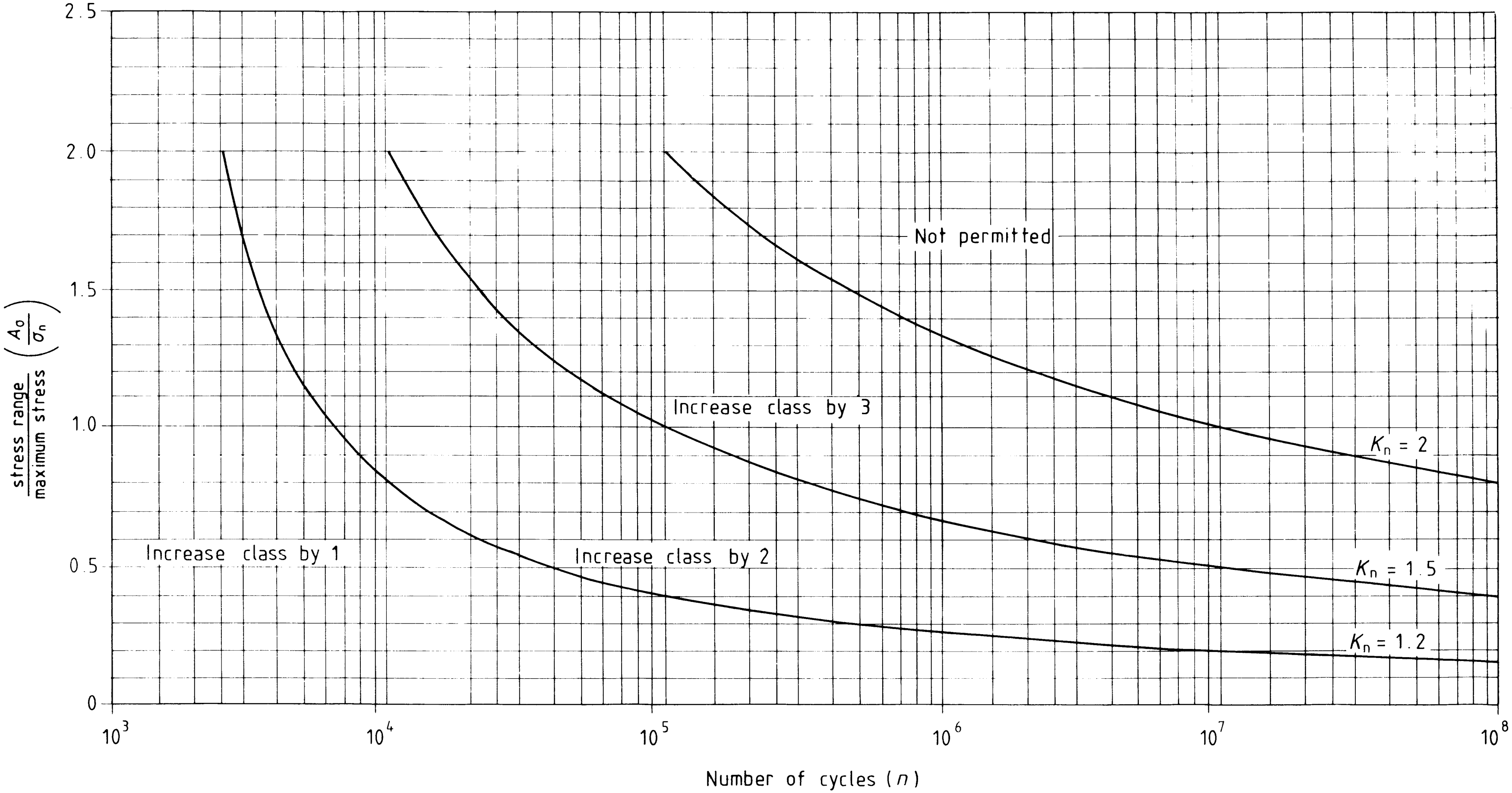


Figure 4.3 — Reduction of strain class ratings as a function of fatigue conditions in service

Section 5. Design for pressure containment

5.1 General

This section gives a range of specific "reference" laminates that should be used for pressure containment. Table 5.1 gives the range and properties of these laminates.

If method A in **4.3.2** is used to select design strain then reference to Table 5.2 to Table 5.5 will provide the required laminate to select from Table 5.1. Should method B in **4.3.3** be used to obtain the design strain then the minimum required design unit modulus for the laminate $X_{\mathrm{LAM\ d}}$ should be calculated in accordance with **5.4**.

A reference laminate with a laminate unit modulus that is equal to or greater than $X_{\mathrm{LAM\ d}}$ should be selected from Table 5.1.

5.2 Pressure ratings

Pipe systems should be rated for one of the following series of pressures expressed in bars[3]:

1, $2^1/_2$, 4, (5), 6, (8), 10,

where the ratings expressed in parentheses should be regarded as "non-preferred".

The pressure rating should be not less than the design pressure, p_{d}, where the design pressure should be not less than:

a) the pressure that will exist in such parts of the system when the pressure-relieving device(s) start(s) to relieve, or the set pressure of the pressure-relieving device(s), whichever is the higher;

b) the maximum pressure that can be attained in service where this pressure is not limited by a relieving device.

The value of the design pressure, p_{d}, to be used in calculations should include the static head where applicable, unless this is taken separately into account in the equation.

5.3 Reference laminates

A range of reference laminates in terms of laminate unit modulus and design thickness is given in Table 5.1 for three types of construction for routine use. These are:

a) *Type 1*. All chopped strand mat construction (CSM) with an internal and external surface tissue reinforced layer.

b) *Type 2*. Chopped strand mat/woven roving construction (CSM/WR) with an internal and external surface tissue reinforced layer. For unlined GRP pipe, there should be a minimum of 1.2 kg/m² of CSM before the first layer of WR is applied.

For thermoplastics-lined GRP pipe, there should be a minimum of 0.6 kg/m² of CSM before the first layer of WR is applied. The ratios of CSM/WR by mass of glass lie within the following ranges.

1) Laminate reference L25 to L30:

$4.0 \leqslant$ (CSM:WR)

2) Laminate reference L40 to L100:

$6.0 \geqslant$ (CSM:WR) $\geqslant 2.5$

3) Laminate reference L120 to L350:

$2.2 \geqslant$ (CSM:WR) $\geqslant 1.1$

In order that bends attain the flexibility and stress factors given in **7.3.1**, material properties for type 2 laminates for bends should be orthotropic with a nominal circumferential/longitudinal ratio of 1 : 1.

c) *Type 3*. Chopped strand mat/filament roving construction (CSM/CF) with an internal and external surface tissue reinforced layer. For unlined GRP pipe, the CSM is on the internal wall after the surface tissue reinforced layer and should be a minimum of 1.2 kg/m² of glass. For thermoplastics-lined GRP pipe, there should be a minimum of 0.6 kg/m² of CSM before the first layer of CF is applied. The values in Table 5.1 are for straight pipes incorporating a winding angle θ of ± 55°.

In order that bends attain the flexibility and stress factors given in **7.3.1**, material properties for type 3 laminates for bends should be orthotropic with a nominal circumferential/longitudinal ratio of 2 : 1.

The modulus of elasticity of the laminate, E_{LAM}, can be calculated by use of equation (4.2) (see **4.2.2.6**).

[3] 1 bar = 10^5 N/m² = 10^5 Pa.

Table 5.1 — Reference laminates and their properties[a]

Laminate reference	Laminate unit modulus X_{LAM}	Design thickness t_d (see **5.5**)			Laminate reference	Laminate unit modulus X_{LAM}	Design thickness t_d (see **5.5**)		
		Type 1	Type 2	Type 3			Type 1	Type 2	Type 3
	N/mm	mm	mm	mm		N/mm	mm	mm	mm
L25	25 000	4.50	4.50		L160	160 000	28.9	21.0	16.3
L30	33 000	6.00	5.50	4.50	L180	180 000	32.5	24.0	18.1
L40	42 000	7.60	6.00	5.20	L200	200 000	36.1	25.5	20.0
L50	50 000	9.00	7.50	5.90	L225	225 000	40.7	29.5	22.4
L60	58 800	10.6	8.50	6.70	L250	250 000	45.2	32.5	24.7
L80	80 000	14.8	11.5	8.70	L275	275 000	49.7	36.0	27.1
L100	100 000	18.1	14.0	10.6	L300	300 000	54.2	39.0	29.4
L120	120 000	21.7	16.5	12.5	L350	350 000	63.3	45.5	34.1
L140	140 000	25.3	19.5	14.4					

[a] To determine values for the modulus of elasticity of the laminate, see **4.2.2.6**.

5.4 Determining reference laminates

The required design strain should be obtained by method A (see **4.3.2**) or by method B (see **4.3.3**).

If the class of pipes has been selected by method A, then the required reference laminate can be obtained directly from Table 5.2 to Table 5.5. Where method B has been used and a design strain obtained that is different from the class ratings then the design unit modulus should be obtained from the following equation:

$$X_{LAM\ d} = \frac{D_i\ p_d E_{LAM}}{(20 E_{LAM} \epsilon_d - p_d)} \qquad (5.1)$$

where

$X_{LAM\ d}$ is the design unit modulus (in N/mm);

D_i is the internal diameter (in mm);

P_d is the design pressure (internal) (gauge) (in bar);

E_{LAM} is the modulus of elasticity of the laminate (in MPa);

ϵ_d is the design strain.

The selected reference laminate should have a unit modulus X_{LAM} that is equal to or greater than the design unit modulus $X_{LAM\ d}$.

5.5 Thickness of reference laminates

Because of the wide range of resin density and glass content it is not possible to give precise values of thickness.

Table 5.6 lists permitted manufacturing tolerances for reference laminates.

For type 3 laminates with winding angles other than ± 55°, the thickness should be calculated using a thickness value of 0.75 mm per kg/m^2 glass.

5.6 Identification of laminate construction

The construction of pipes and fittings should be identified by type (see **5.3**), laminate reference number (see Table 5.1) and nominal size (see, e.g. Table 5.4), e.g. TYPE 1 – L 100 – 600.

Table 5.2 — Reference laminates for construction of class 1 systems (see **4.3.2**)

Nominal pipe size	Pressure ratings (bar)						
	1	$2^1/_2$	4	5	6	8	10
40	L25	L25	L25	L25	L25	L25	L25
50	L25	L25	L25	L25	L25	L25	L25
80	L25	L25	L25	L25	L25	L25	L30
100	L25	L25	L25	L25	L25	L30	L40
150	L25	L25	L25	L25	L30	L40	L50
200	L25	L25	L25	L30	L40	L50	L60
250	L30[a]	L30[a]	L30	L40	L50	L60	L80
300	L30[a]	L30	L40	L50	L60	L80	L100
350	L30	L30	L40	L60	L80	L100	L120
400	L30	L30	L50	L60	L80	L100	L120
450	L30	L30	L60	L80	L80	L120	L140
500	L30	L40	L60	L80	L100	L120	L160
550	L30	L40	L80	L80	L100	L140	L180
600	L30	L50	L80	L100	L120	L160	L180
650	L30	L50	L80	L100	L120	—	—
700	L30	L50	L100	L120	L140	—	—
750	L30	L60	L100	L120	L140	—	—
800	L30	L60	L100	L120	L140	—	—
850	L30	L80	L100	L140	L160	—	—
900	L30	L80	L120	L140	L160	—	—
950	L30	L80	L120	L140	L180	—	—
1 000	L30	L80	L120	L160	L180	—	—
1 050	L30	L80	L120	L160	L200	—	—
1 100	L30	L80	L140	L160	L200	—	—
1 150	L30	L100	L140	L180	L200	—	—
1 200	L40	L100	L140	L180	L225	—	—

[a] L25 may be used with a thermoplastics liner.

Table 5.3 — Reference laminates for construction of class 2 systems (see **4.3.2**)

Nominal pipe size	Pressure ratings (bar)						
	1	$2^1/_2$	4	5	6	8	10
40	L25	L25	L25	L25	L25	L25	L25
50	L25	L25	L25	L25	L25	L25	L25
80	L25	L25	L25	L25	L25	L25	L30
100	L25	L25	L25	L25	L25	L30	L40
150	L25	L25	L25	L25	L30	L40	L50
200	L25	L25	L30	L40	L40	L60	L80
250	L30[a]	L30[a]	L40	L50	L60	L80	L100
300	L30[a]	L30	L50	L60	L80	L100	L120
350	L30	L30	L50	L80	L80	L100	L140
400	L30	L40	L60	L80	L100	L120	L160
450	L30	L40	L80	L80	L100	L140	L160
500	L30	L50	L80	L100	L120	L160	L180
550	L30	L50	L80	L100	L120	L160	L200
600	L30	L60	L100	L120	L140	L160	L225
650	L30	L60	L100	L120	L140	—	—
700	L30	L80	L100	L140	L160	—	—
750	L30	L80	L120	L140	L160	—	—
800	L30	L80	L120	L160	L180	—	—
850	L30	L80	L120	L160	L180	—	—
900	L30	L80	L140	L160	L200	—	—
950	L30	L100	L140	L180	L200	—	—
1 000	L40	L100	L140	L180	L225	—	—
1 050	L40	L100	L160	L200	L225	—	—
1 100	L40	L100	L160	L200	L250	—	—
1 150	L40	L100	L160	L200	L250	—	—
1 200	L40	L120	L180	L225	L275	—	—

[a] L25 may be used with a thermoplastics liner.

Table 5.4 — Reference laminates for construction of class 3 systems (see **4.3.2**)

Nominal pipe size	Pressure ratings (bar)						
	1	$2^1/_2$	4	5	6	8	10
40	L25	L25	L25	L25	L25	L25	—
50	L25	L25	L25	L25	L25	L25	—
80	L25	L25	L25	L25	L25	L30	—
100	L25	L25	L25	L25	L30	L40	—
150	L25	L25	L30	L40	L40	L60	—
200	L25	L25	L40	L50	L60	L80	—
250	L30[a]	L30[a]	L50	L60	L80	L100	—
300	L30[a]	L40	L60	L80	L100	L120	—
350	L30	L40	L80	L80	L100	L140	—
400	L30	L50	L80	L100	L120	L160	—
450	L30	L50	L80	L100	L120	L160	—
500	L30	L60	L100	L120	L140	L180	—
550	L30	L80	L100	L140	L160	L200	—
600	L30	L80	L120	L140	L160	L225	—
650	L30	L80	L120	—	—	—	—
700	L30	L80	L140	—	—	—	—
750	L30	L100	L140	—	—	—	—
800	L40	L100	L140	—	—	—	—
850	L40	L100	L160	—	—	—	—
900	L40	L100	L160	—	—	—	—
950	L40	L120	L180	—	—	—	—
1 000	L50	L120	L180	—	—	—	—
1 050	L50	L120	L200	—	—	—	—
1 100	L50	L120	L200	—	—	—	—
1 150	L50	L140	L200	—	—	—	—
1 200	L60	L140	L225	—	—	—	—

[a] L25 may be used with a thermoplastics liner.

Table 5.5 — Reference laminates for construction of class 4 systems (see **4.3.2**)

Nominal pipe size	Pressure ratings (bar)						
	1	$2^1/_2$	4	5	6	8	10
40	L25	L25	L25	L25	L25	—	—
50	L25	L25	L25	L25	L25	—	—
80	L25	L25	L25	L30	L30	—	—
100	L25	L25	L30	L40	L40	—	—
150	L25	L25	L40	L50	L60	—	—
200	L25	L30	L50	L60	L80	—	—
250	L30[a]	L40	L60	L80	L100	—	—
300	L30[a]	L50	L80	L100	L120	—	—
350	L30	L60	L100	L120	L140	—	—
400	L30	L60	L100	L120	L160	—	—
450	L30	L80	L120	L140	L180	—	—
500	L30	L80	L120	L160	L180	—	—
550	L30	L80	L140	L180	L200	—	—
600	L40	L100	L160	L180	L225	—	—
650	L40	L100	—	—	—	—	—
700	L40	L120	—	—	—	—	—
750	L50	L120	—	—	—	—	—
800	L50	L120	—	—	—	—	—
850	L50	L140	—	—	—	—	—
900	L60	L140	—	—	—	—	—
950	L60	L140	—	—	—	—	—
1 000	L60	L160	—	—	—	—	—
1 050	L80	L160	—	—	—	—	—
1 100	L80	L160	—	—	—	—	—
1 150	L80	L180	—	—	—	—	—
1 200	L80	L180	—	—	—	—	—

[a] L25 may be used with a thermoplastics liner.

Table 5.6 — Permitted manufacturing tolerances for reference laminates for straight pipes

Type of laminate (see **5.3**)	Permissible deviations, per cent, relative to design thickness t_d (see Table 5.1)
1	$t_d \pm 20$ %
2	$t_d \pm 25$ %
3	$t_d \pm 20$ %

Section 6. Allowable vacuum rating for pipes made using reference laminates

6.1 Determination of allowable vacuum

The maximum permissible external pressure for a pipe constructed from a reference laminate (see Table 5.1) without stiffening rings should be determined by the equation:

$$P_e = (20X_{LAM}/t_d F_s)\ \{t_d/(D_i + 2t_d)\}^3 \quad (6.1)$$

where

- P_e is the allowable external pressure (in bar);
- X_{LAM} is the laminate unit modulus (in N/mm);
- t_d is the design thickness of the reference laminate (in mm);
- D_i is the internal diameter of the pipe (in mm);
- F_s is the factor of safety (4 unless otherwise agreed).

6.2 Increasing allowable external pressure

Where the allowable external pressure determined in accordance with **6.1** is too low for the intended duty the following options are available.

a) To use a reference laminate with a higher unit modulus.

b) To use stiffening rings.

If option a) is to be used then the calculation in **6.1** should be repeated with the new laminate unit modulus being used, otherwise see **6.3**.

6.3 Stiffening rings

If it has been decided to use stiffening rings the following equations should be used to calculate the distance between stiffening rings and the second moment of area (moment of inertia) of the stiffening ring:

a) Distance between stiffening rings

$$J = (25X_{LAM}/F_s\, p_e)\ \{t_d/(D_i + 2t_d)\}^{1.5} \quad (6.2)$$

b) Second moment of area

$$I = 0.018\ (D_i + 2t_d)\ JD_{na}^{\ 2} p_e t_d/X_{LAM} \quad (6.3)$$

where

- I is the second axial moment of area of the stiffening ring section about its neutral axis (in mm^4);
- J is the distance between stiffening rings (in mm);
- D_{na} is the diameter of the neutral axis of the stiffening ring (in mm).

The permissible length of shell, J_s, which may be regarded as effectively contributing to the amount of the stiffening ring section should be obtained from the following equation providing that J_s is not taken to be greater than J:

$$J_s = 0.75\ \{(D_i + 2t_d)t_d\}^{0.5} \quad (6.4)$$

where

- J_s is the length of shell (in mm);
- D_i is the internal diameter of the pipe (in mm);
- t_d is the design thickness of the reference laminate (in mm).

Section 7. Flexibility and stress analyses and factors

7.1 General

Pipes and pipeline components in glass reinforced plastics can be considered in the same way as components in any other material with the same form of flexibility and stress intensification factors. The flexibility factor is the ratio of the flexibility of the component to the flexibility of an equivalent straight pipe. Similarly the stress intensification factors are each a ratio of the peak stress in a component under a loading system to the stress in equivalent straight pipe. Supporting information is given in Appendix C and through references.

With the range of constructions available and the relative ease of fabrication in different thicknesses and other dimensions it is essential that details of the component and the class of pipe are available as well as the stress parameters. The method of fabrication can introduce variations in thickness of a component which must be kept within limits to ensure the reliability of the stress factors.

The maximum stress used in the calculation of stress factors is the maximum membrane stress in the direction of the component axis and for the preferred material direction.

By the nature of the materials in resin and glass, the modulus of glass reinforced plastics materials is low compared with metals and high local deformation may occur at relatively low stresses. In such cases consideration should be given to the possibility of elastic instability.

7.2 Calculation of temperature change for flexibility analysis

7.2.1 Pipe laminate

When considering heating or cooling of the uninsulated pipe wall by the process fluid the mean temperature change of the pipe wall should be calculated using as applicable equation (7.1) if heating occurs or equation (7.2) if cooling occurs, these equations being:

$$\Delta T_d = k\,(T_p - T_a) \qquad (7.1)$$

$$\Delta T_d = k\,(T_a - T_p) \qquad (7.2)$$

where

- ΔT_d is the design temperature change to be used for flexibility analysis;
- T_p is the process temperature;
- T_a is the ambient temperature;
- k is to be taken as 0.85 for liquids and 0.8 for gases.

For expansion the lowest encountered ambient temperature should apply and for contraction the highest encountered ambient temperature should apply.

In some circumstances changes in ambient temperature can be more important in the design of the piping 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 assumed erection temperature. Further guidance and examples on the significance of thermal effects in flexibility and stress analyses are given in Appendix C.

7.2.2 Extension due to pressure

A longitudinal strain ϵ_{xp} is produced when a pipe is pressurized. To enable this to be included in the flexibility calculation the longitudinal strain can be represented by an equivalent increase in temperature calculated from the following equation:

$$\Delta T_e = \frac{p(D_i + t_d)}{20\alpha_\ell}\left(\frac{1}{2X_{\mathrm{LAM}x}} - \frac{\nu_{\Phi x}}{X_{\mathrm{LAM}\,\Phi}}\right) \qquad (7.3)$$

where

- ΔT_e is the increase in temperature necessary to produce longitudinal strain equivalent to ϵ_{xp} (in K);
- p is the internal pressure (gauge) (in bar);
- D_i is the internal diameter of the pipe (in mm);
- t_d is the design thickness of the reference laminate (in mm);
- α_ℓ is the linear thermal expansion coefficient, in K^{-1}, for the laminate in the longitudinal direction;
- $\upsilon_{\phi x}$ is the Poisson ratio giving strain in the longitudinal direction caused by stress in the circumferential direction;
- $X_{\mathrm{LAM}\,x}$ is the laminate unit modulus (in N/mm) in the longitudinal direction;
- $X_{\mathrm{LAM}\,\phi}$ is the laminate unit modulus (in N/mm) in the circumferential direction.

NOTE For type 1 and type 2 pipes (see Table 4.2), where $X_{\mathrm{LAM\,x}} = X_{\mathrm{LAM\,Ã}}$ and $\upsilon_\phi x = \frac{1}{3}$, equation (7.3) simplifies to become:

$$T_e = p(D_i + t_d)/120\,X_{\mathrm{LAM}}\,\alpha_\ell$$

7.3 Stress analysis of flexible piping systems

7.3.1 Factors for bends

7.3.1.1 *Flexibility factors*. Because of ovalization of the cross section during bending, the flexibility of a pipe bend is greater than that of an equivalent length of straight pipe of the same wall construction and diameter. The ratio of these flexibilities is known as the flexibility factor and is calculated by the following equation:

$$\kappa = \kappa_b/\kappa_s \quad (7.4)$$

where

κ is the flexibility factor;

κ_b is the flexibility of a bend;

κ_s is the flexibility of a straight.

These are taken for both in-plane (suffix i) and out-of-plane (suffix o) bending.

Thus, if the flexibility factors are known for a particular bend, simple beam theory can be used to predict end loads and deflection.

Subject to a correction factor (see **7.3.1.3**), the flexibility factors are primarily a function of the pipe factor. The flexibility factors and pipe factors are given by equations (7.5) and (7.6) respectively:

$$\kappa_{(i\ or\ o)} = \alpha_1 \lambda_b y_1 \quad (7.5)$$

$$\lambda_b = t_d R/r^2 \quad (7.6)$$

where

λ_b is the pipe factor applicable to a bend;

α_1 and y_1 are experimentally determined coefficients and powers respectively (see **7.3.1.2**);

t_d is the design thickness of the reference laminate (in mm);

R is the mean pipe bend radius (in mm);

r is the pipe bore radius (in mm).

7.3.1.2 *Constants for calculating flexibility factors for bends under zero gauge pressure*. Because of the methods of fabrication the pipe wall thickness for GRP bends is variable and irregular. A survey of bends from a variety of commercial sources revealed that the wall thickness at the, intrados ranges from 1.1 times to 2 times the nominal value and at the extrados ranges from 1 times to 1.5 times the nominal value, i.e. the maximum anticipated mean wall thickness for commercially fabricated bends is 1.75 times the nominal value.

The values given in Figure 7.1 for y [see equation (7.5)] for smooth and mitred bends respectively and given for α for the three laminate types as applicable are considered adequate for pipe bends with a mean wall thickness around the intrados of 1.75 times the nominal value or less (see NOTE) and provided that for type 3 laminates the circumferential stiffness: longitudinal stiffness ratio for the laminate (e.g. $X_{LAM\,\phi}/X_{LAM\,x}$ or $E_{LAM\,\phi}/E_{LAM\,x}$) is not greater than 2 : 1 (see Figure 4.1).

Values for κ_i and κ_o may be obtained as a function of λ_b directly from Figure 7.2 and Figure 7.3 for smooth or mitred bends respectively for pipes not subject to internal pressure (otherwise see **7.3.1.3**).

NOTE If the wall thickness exceeds this limit, it will be necessary to measure its flexibility and that of an equivalent straight under in-plane bending. For guidance on how to undertake such evaluations, attention is drawn to reference [1] and also to the great difficulty in obtaining reliable values from experimental results, particularly for small diameter pipes, because of the ill-conditioned equation which has to be used.

7.3.1.3 *Correction factor for internal pressure*. The flexibility of pipe bends with low pipe factors (large bore/thin wall) is affected by internal pressure. This reduces the tendency of the bend to ovalize and hence decreases the flexibility factor. The correction factor γ can be calculated from the following equation (which is reproduced for convenience in Figure 7.1: for background information, attention is drawn to reference [1]).

$$\gamma = [1 + 2.53\epsilon_d R^{1/3} r t_d^{-4/3}]^{-1} \quad (7.7)$$

where

ϵ_d is the design strain;

R is the mean pipe bend radius (in mm);

r is the pipe bore radius (in mm);

t_d is the design thickness of the reference laminate (in mm).

7.3.1.4 *Stress intensity factors for bends*. Because of ovalization of the cross section during bending the stresses in a pipe bend are greater than those in a straight pipe of the same wall construction and diameter under the same bending moment. These ratios are known as the stress intensification factors (SIFs) and are obtained from the following equation:

$$SIF_b = \sigma_{max\,b}/\sigma_{max\,s} \quad (7.8)$$

where

SIF_b is the stress intensification factor;

$\sigma_{max\,b}$ is the maximum stress in bend (in MPa);

$\sigma_{max\,s}$ is the maximum stress in straight (in MPa).

Four *SIFs* are required to quantify the principal stresses in a bend, i.e.:

a) longitudinal *SIF* under in-plane bending (suffix *xi*);

b) circumferential *SIF* under in-plane bending (suffix ϕi);

c) longitudinal *SIF* under out-of-plane bending (suffix *xo*);

d) circumferential *SIF* under out-of-plane bending (suffix ϕo).

As with the flexibility factors the stress intensification factors are primarily functions of the pipe factor, in this case λ_b [see equation (7.6)], and may be subject to a correction factor (see **7.3.1.6**) and, additionally, a pressure stress multiplier (see **7.3.1.7**).

These functions take the form

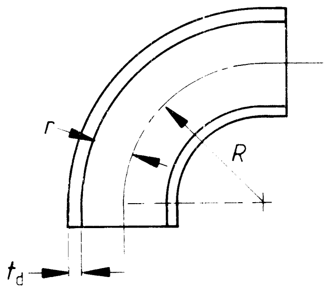
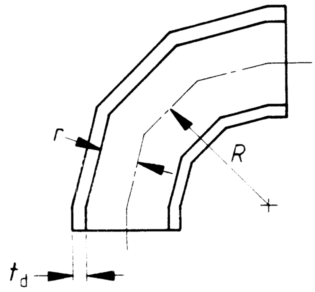
$$SIF_b = \alpha_2 \lambda_b^{y2} \qquad (7.9)$$

where

α_2 and y_2 are experimentally determined coefficients and powers, respectively (see **7.3.1.5**).

7.3.1.5 *Constants for calculating stress intensification factors for bends under zero gauge pressure*. The variation in pipe wall thickness discussed in **7.3.1.2** makes accurate prediction of maximum stresses in bends impossible. The approach adopted in this standard is to provide values which are unlikely to be exceeded in practice. A survey of a range of pipes from a variety of sources revealed that the lower bound mean thickness of the pipe wall in the region of the intrados is 1.1 times the nominal value. The value given in Figure 7.1 for y_2 [see equation (7.9)] and given for α_2 for each of the three laminate types for smooth and mitred bends respectively are valid for bends which are known to have a mean crotch wall thickness of at least 1.1 times the nominal value. If it is suspected that a pipe bend or a batch of bends are below this limit, it will be necessary to determine, by testing, the stress intensification factors.

Values for SIF_{xi}, $SIF_{\phi i}$, SIF_{xo} and $SIF_{\phi o}$ can be obtained as a function of λ_b directly from Figure 7.4 to Figure 7.11 inclusive, as applicable.

Bends	Type	
	Smooth	Mitred
		
Pipe factor	$\lambda_b = \frac{t_d R}{r^2}$ (7.6)[a]	

Flexibility factor		$\kappa = \gamma\alpha_1\lambda^{y1 (= -1)}$ (7.5)[a]			$\kappa = \gamma\alpha_1\lambda^{y1 (= -0.83)}$ (7.5)[a]		
Laminate type		**1**	**2**	**3**	**1**	**2**	**3**
α_1	**In-plane**	1.0	1.0	0.7	0.9	0.9	0.64
	Out-of-plane	1.0	1.0	0.7	0.9	0.9	0.64
Correction factor		$\gamma = (1 + 2.53\ \epsilon_d R^{1/3} r t_d^{-4/3})^{-1}$ (7.7)[a]					

Stress intensification factor			$SIF = (\delta_x \text{ or } \delta_\phi)\alpha_2\lambda^{y2\ (=-2/3)}$ (7.9)[a]					
Laminate type			**1**	**2**	**3**	**1**	**2**	**3**
α_2	**In-plane**	**Long.**	0.96	0.96	0.76	0.65	0.69	0.5
		Circ.	1.84	1.60	1.60	1.47	1.37	1.2
	Out-of-plane	**Long.**	1.1	1.03	0.56	0.86	0.86	0.51
		Circ.	1.8	1.42	1.58	1.72	1.4	1.53
Correction factor		**Long.**	$\delta_x = (1 + 2.53\ \epsilon_d R^{1/3} r t_d^{-4/3})^{-1}$ (7.10)[a]					
		Circ.	$\delta_\phi = (1 + 1.1\ \epsilon_d R^{2/3} r^{5/6} t_d^{-3/2})^{-1}$ (7.11)[a]					
Pressure stress multiplier *m*			1.0 or $0.83(1 - r/2R)/(1 - r/R)$ whichever is the greater (see **7.3.1.7**)			1.3		

[a] Equation references.

Figure 7.1 — Types of bends and associated factors

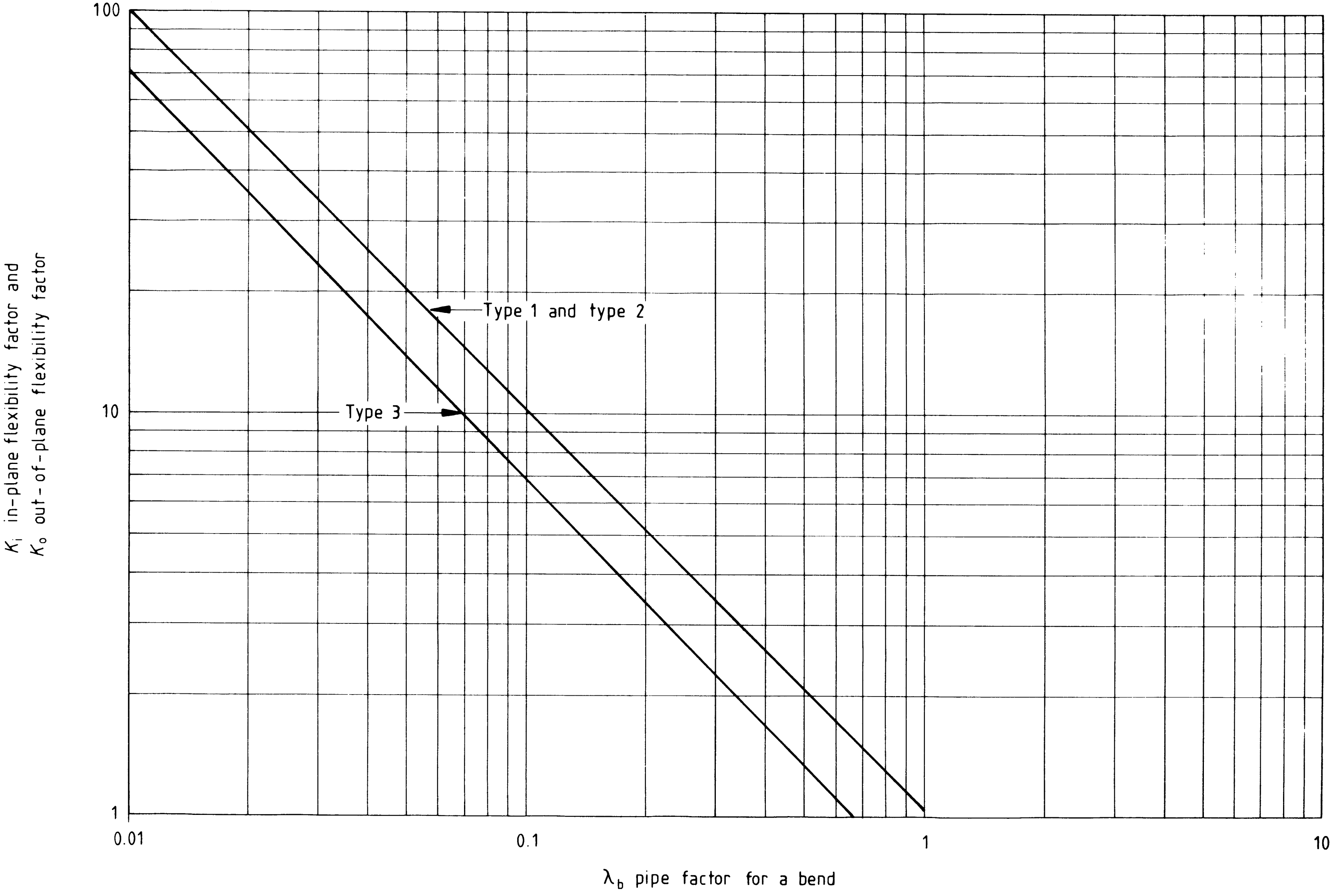


Figure 7.2 — Flexibility factors for smooth bends (see **7.3.1.1** and **7.3.1.2**)

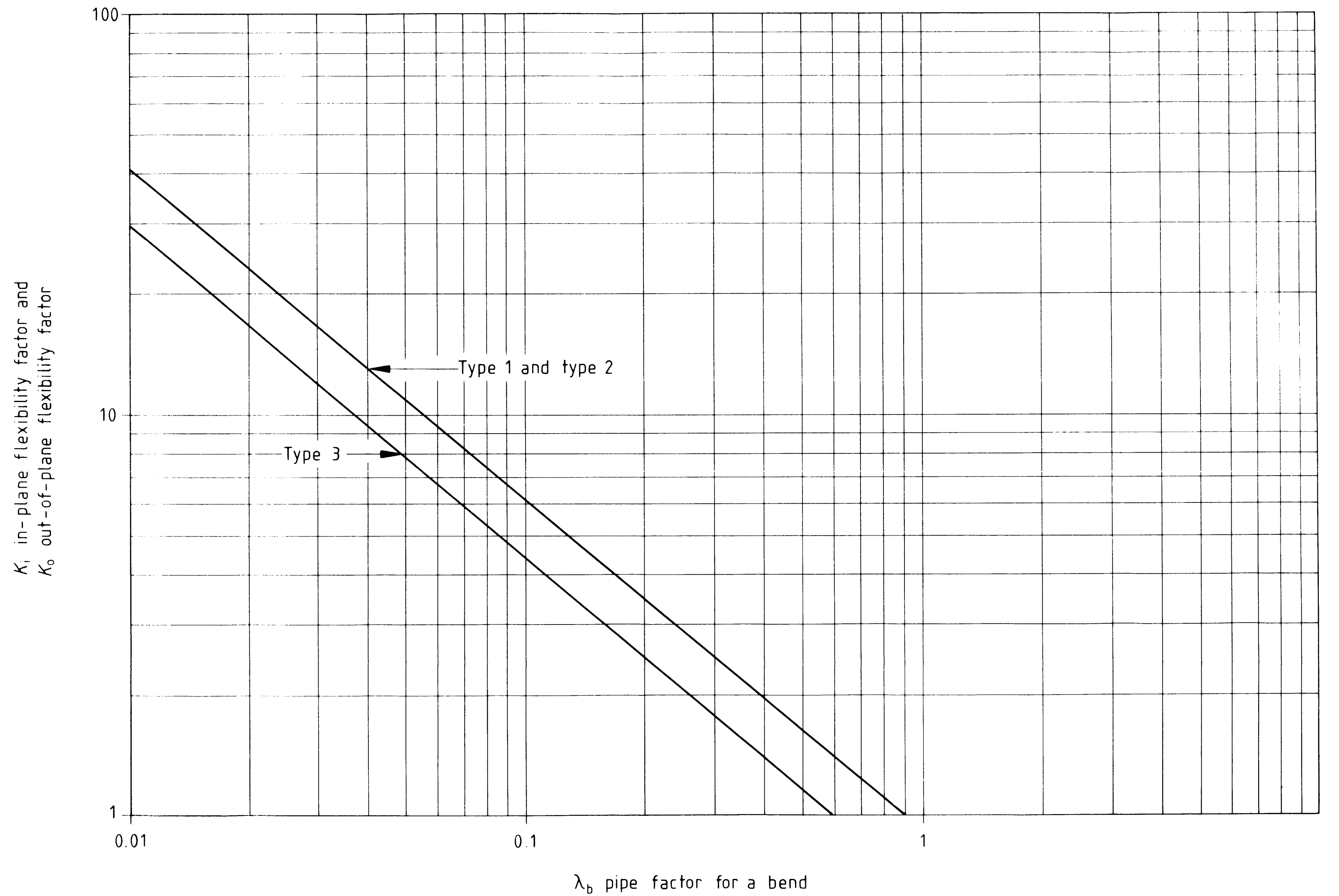


Figure 7.3 — Flexibility factors for mitred bends (see **7.3.1.1** and **7.3.1.2**)

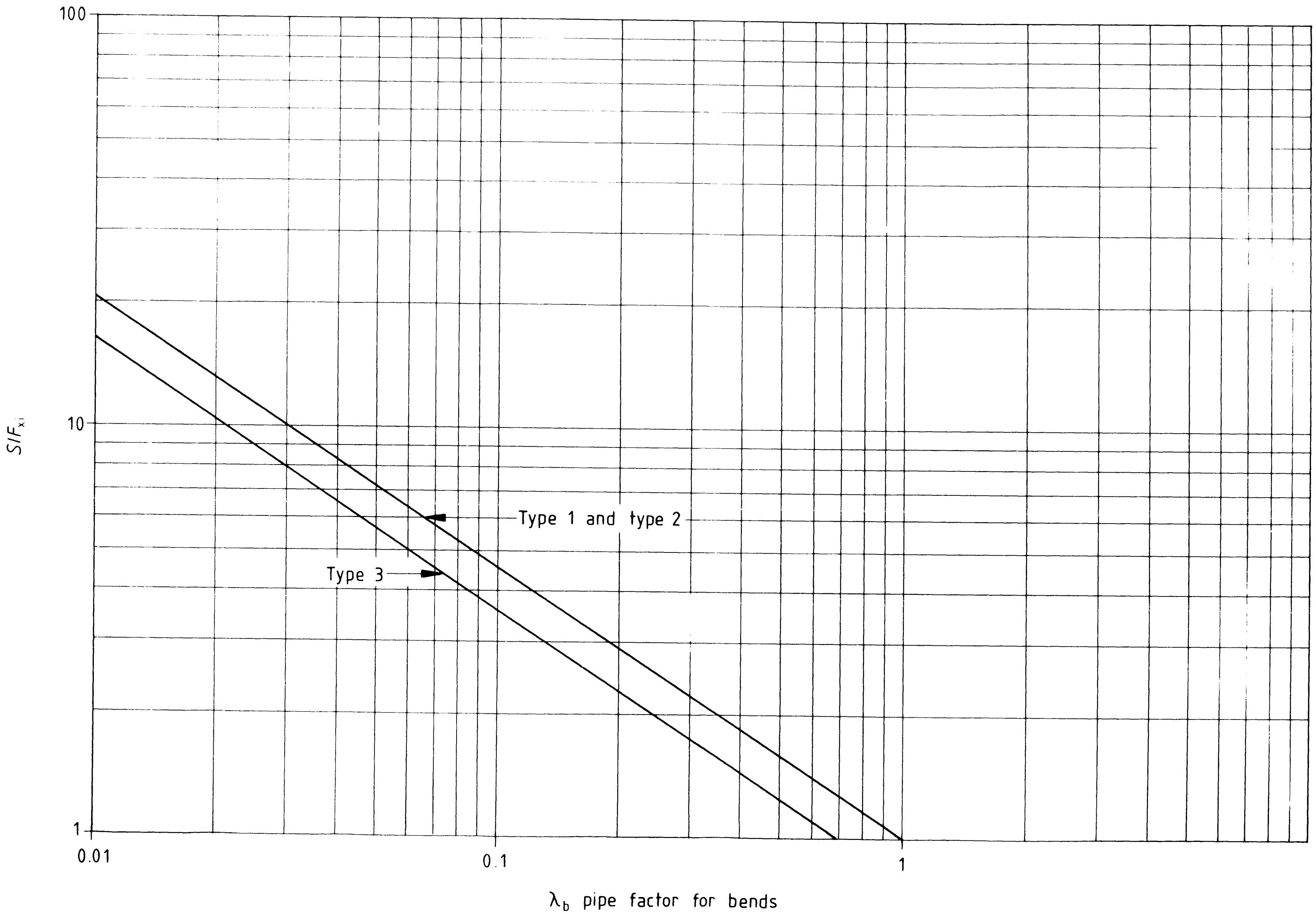


Figure 7.4 — In-plane longitudinal SIFs for smooth bends

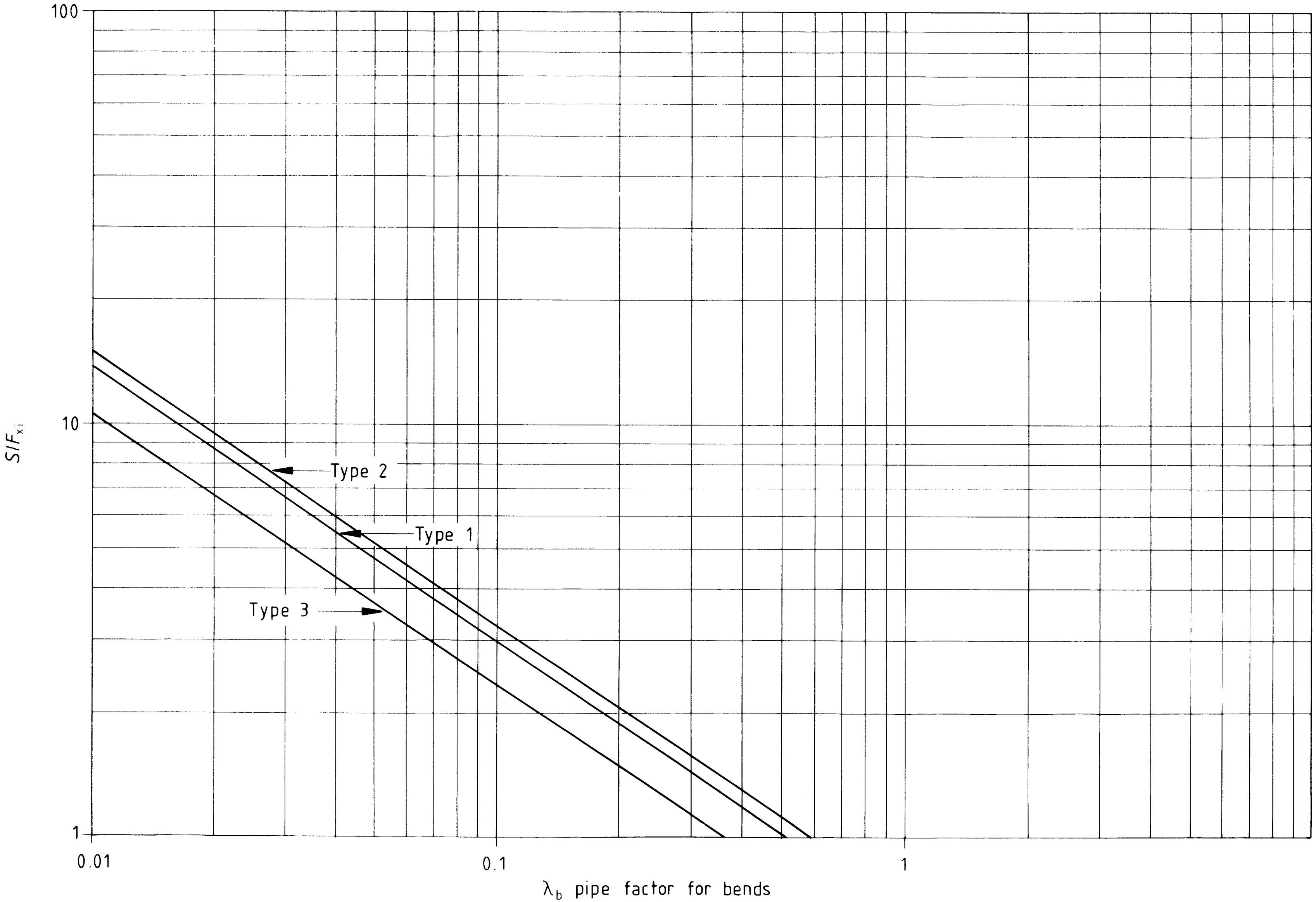


Figure 7.5 — In-plane longitudinal SIFs for mitred bends

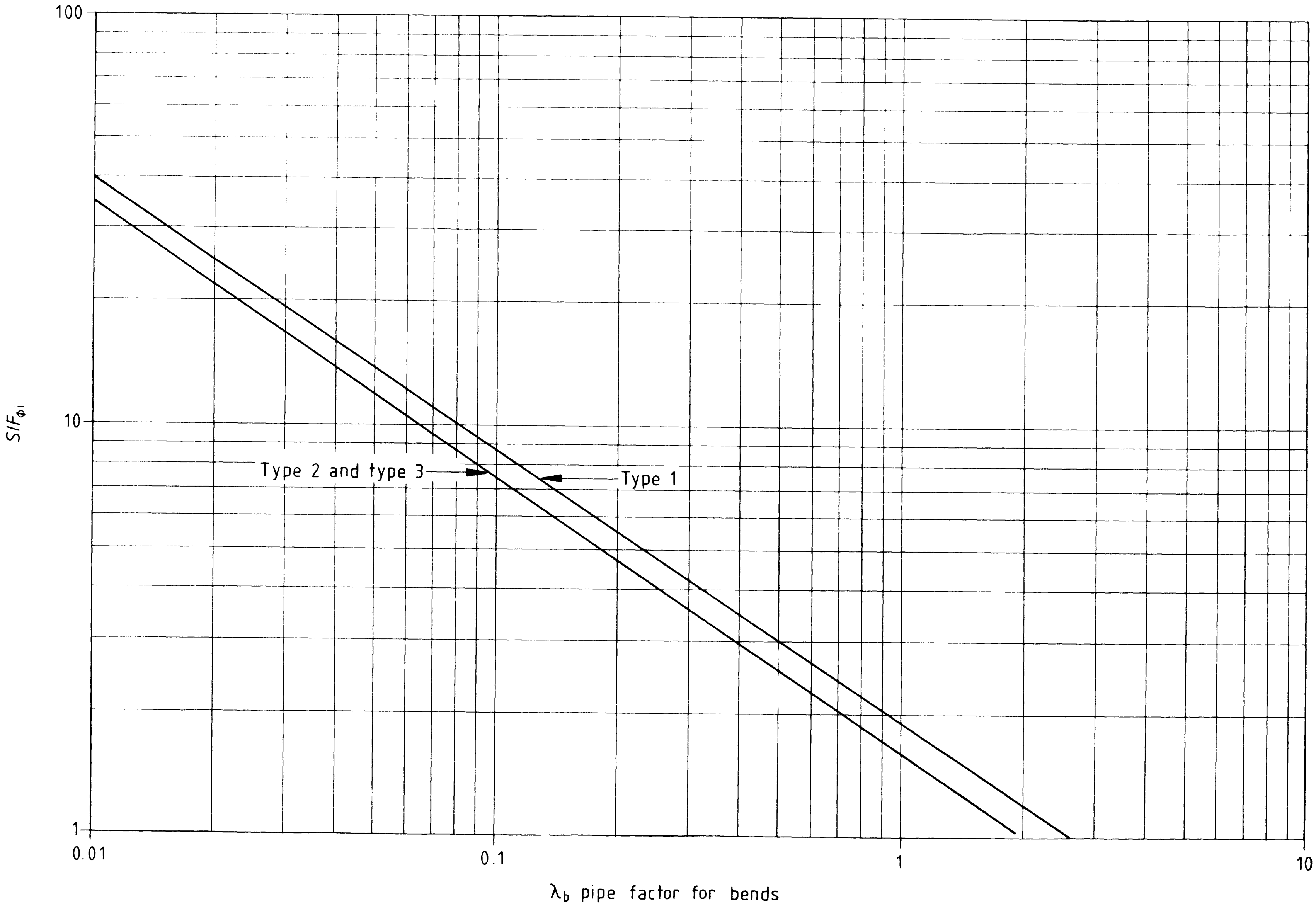


Figure 7.6 — In-plane circumferential SIFs for smooth bends

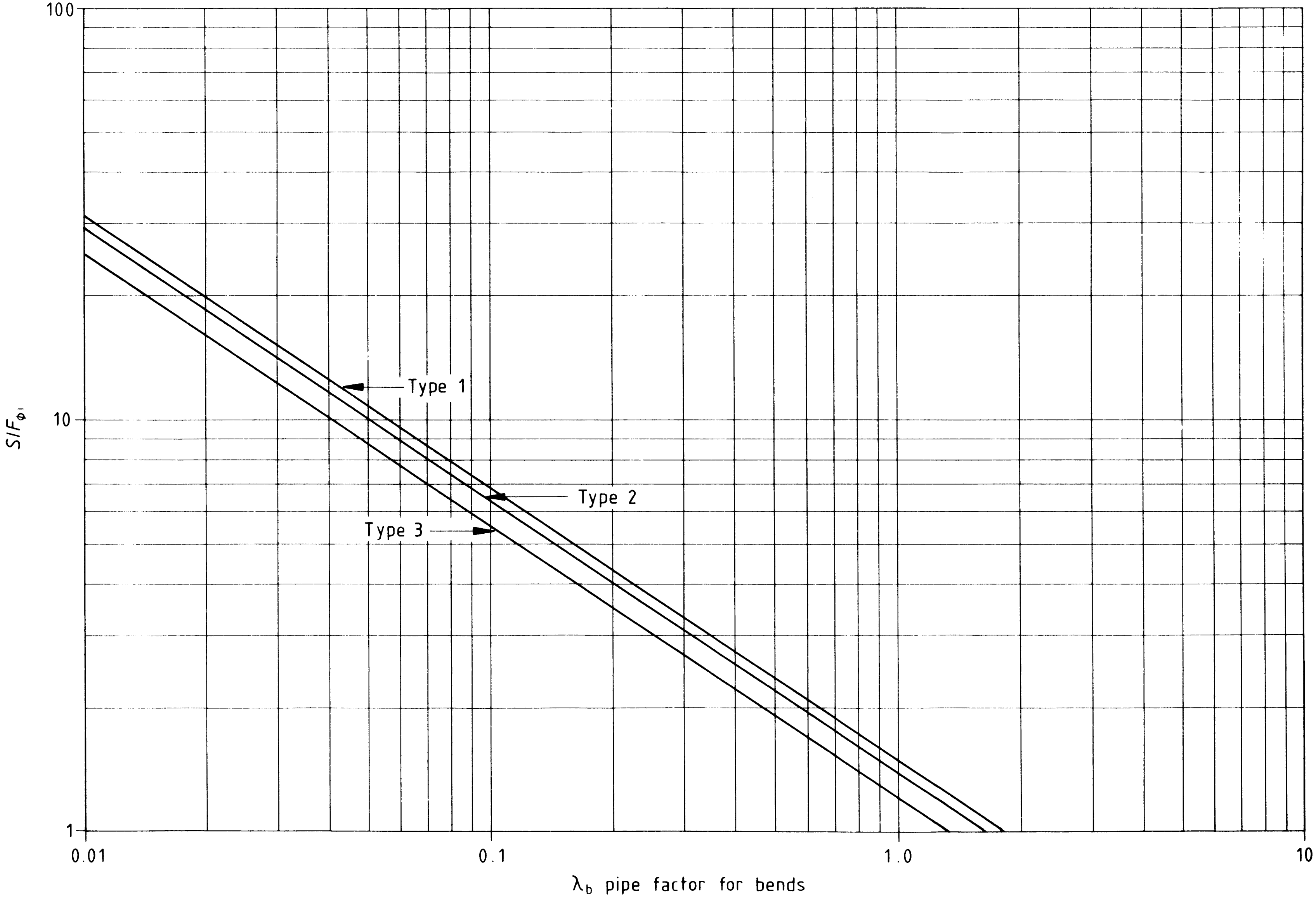


Figure 7.7 — In-plane circumferential SIFs for mitred bends

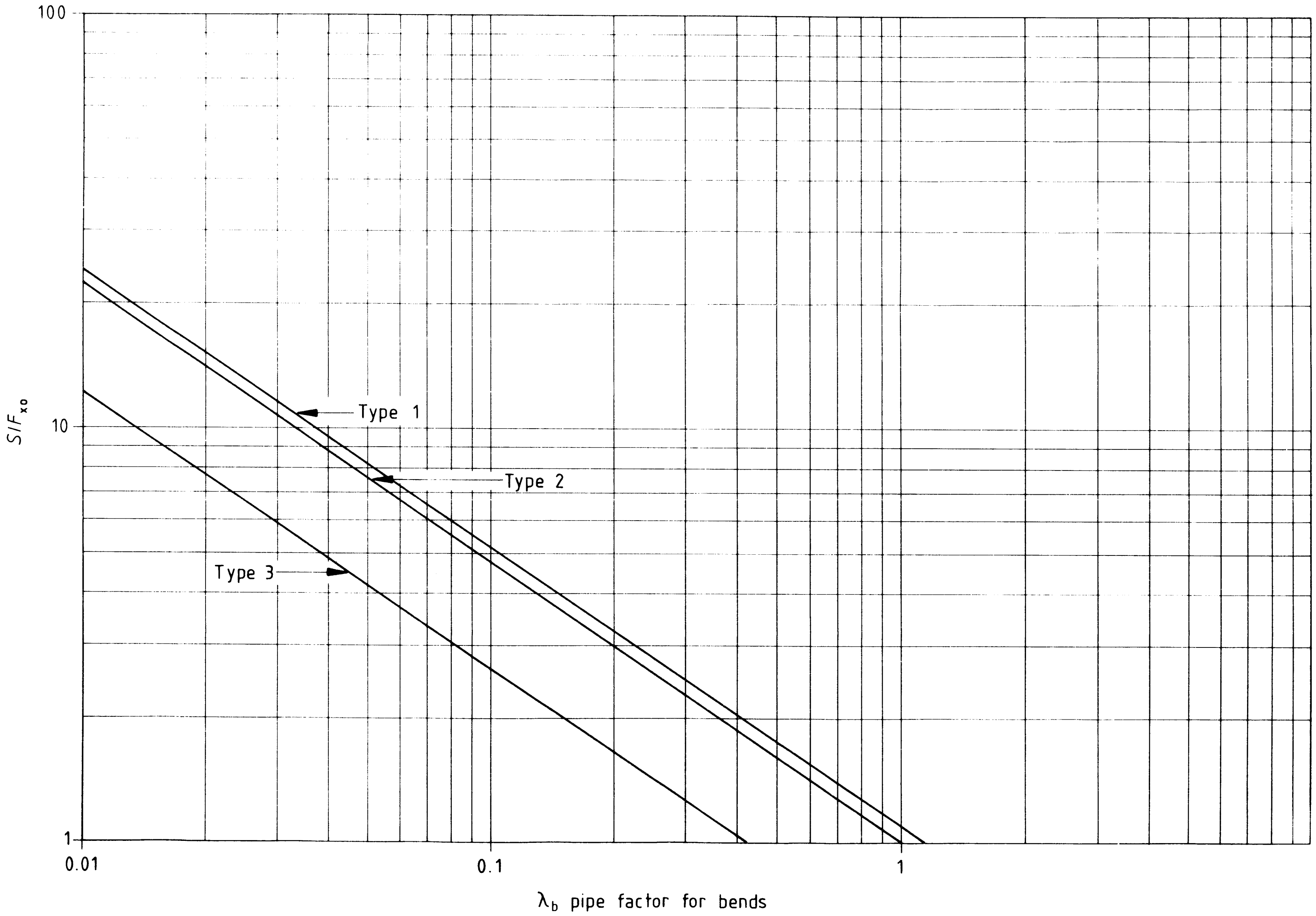


Figure 7.8 — Out-of-plane longitudinal SIFs for smooth bends

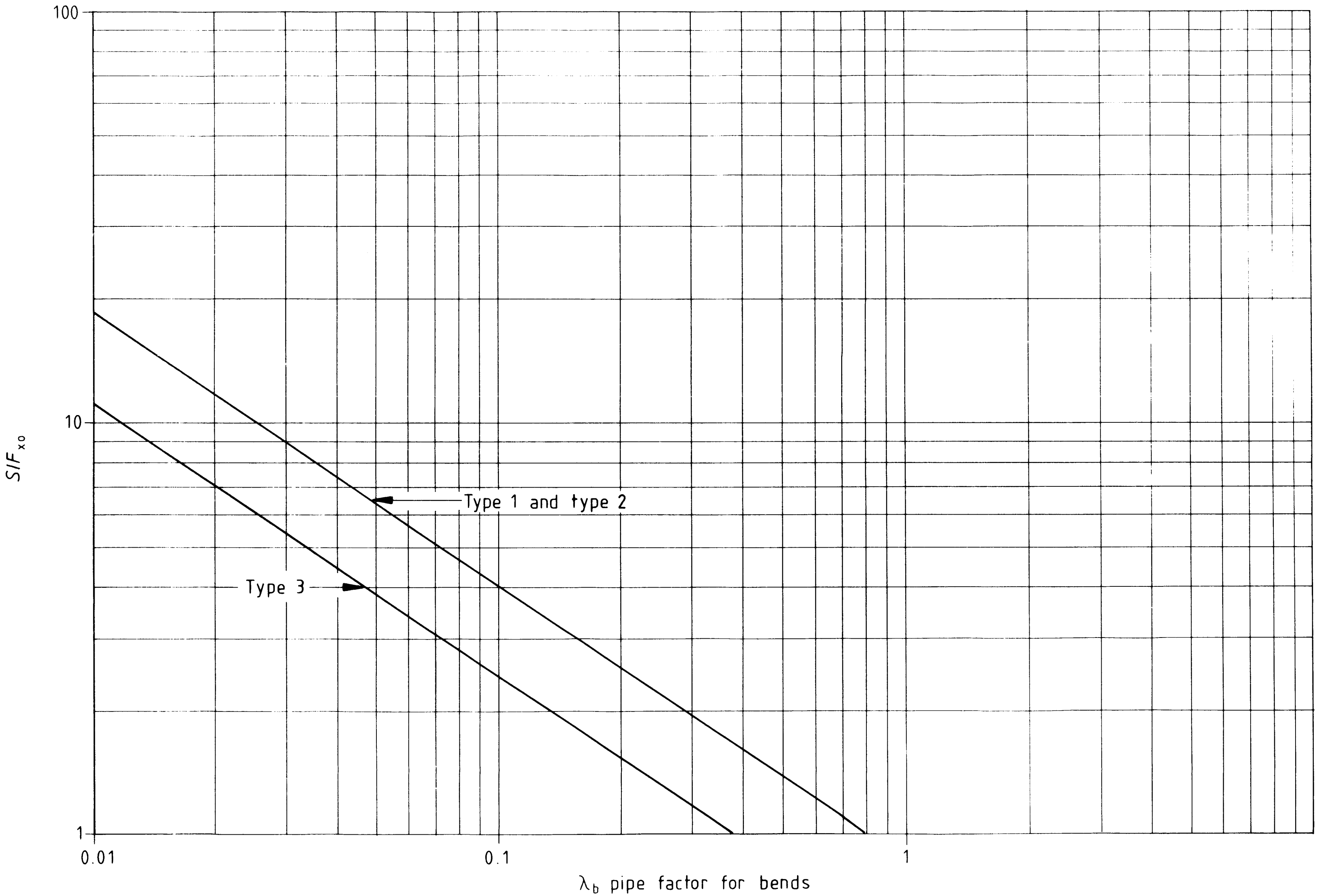


Figure 7.9 — Out-of-plane longitudinal SIFs for mitred bends

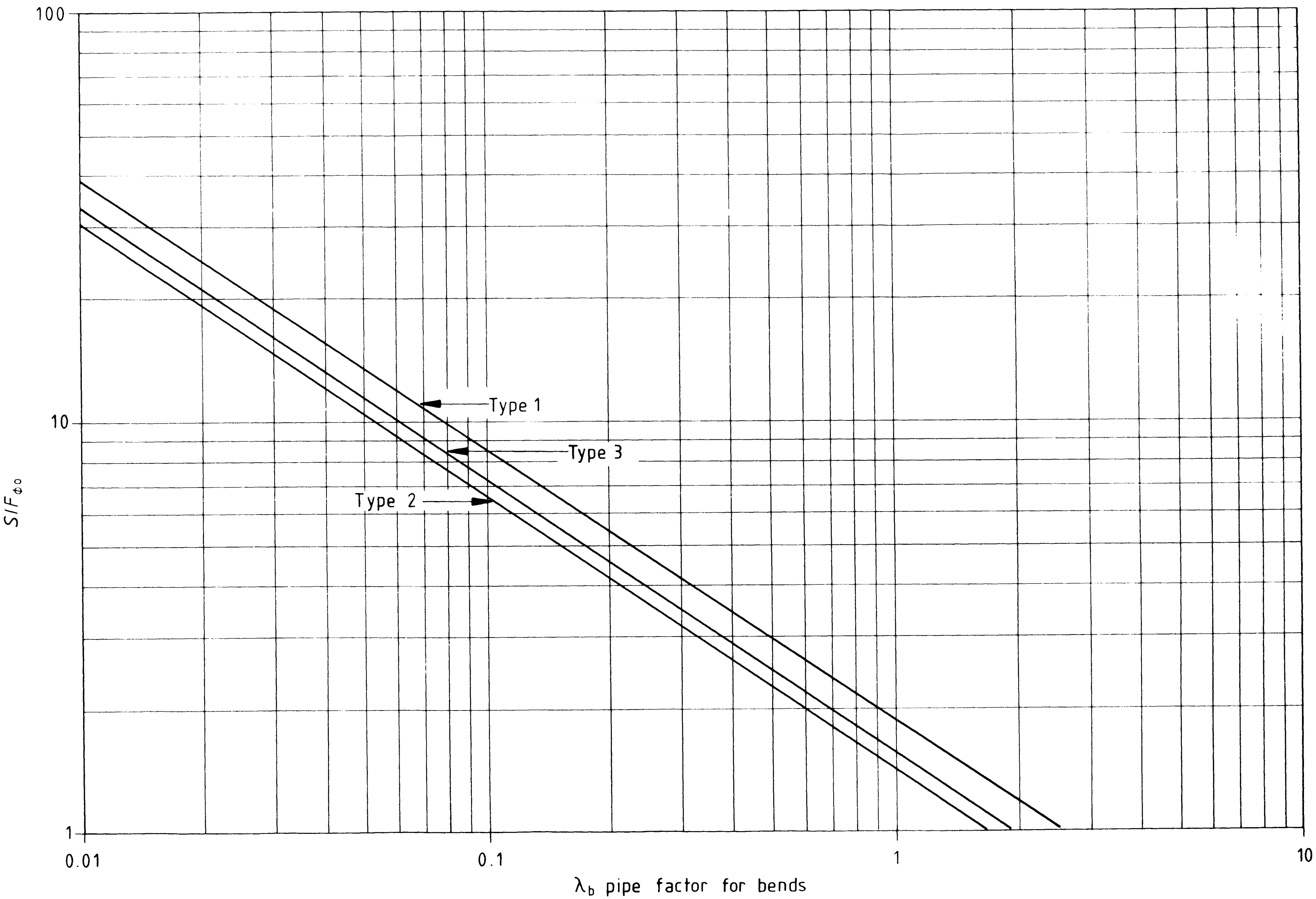


Figure 7.10 — Out-of-plane circumferential SIFs for smooth bends

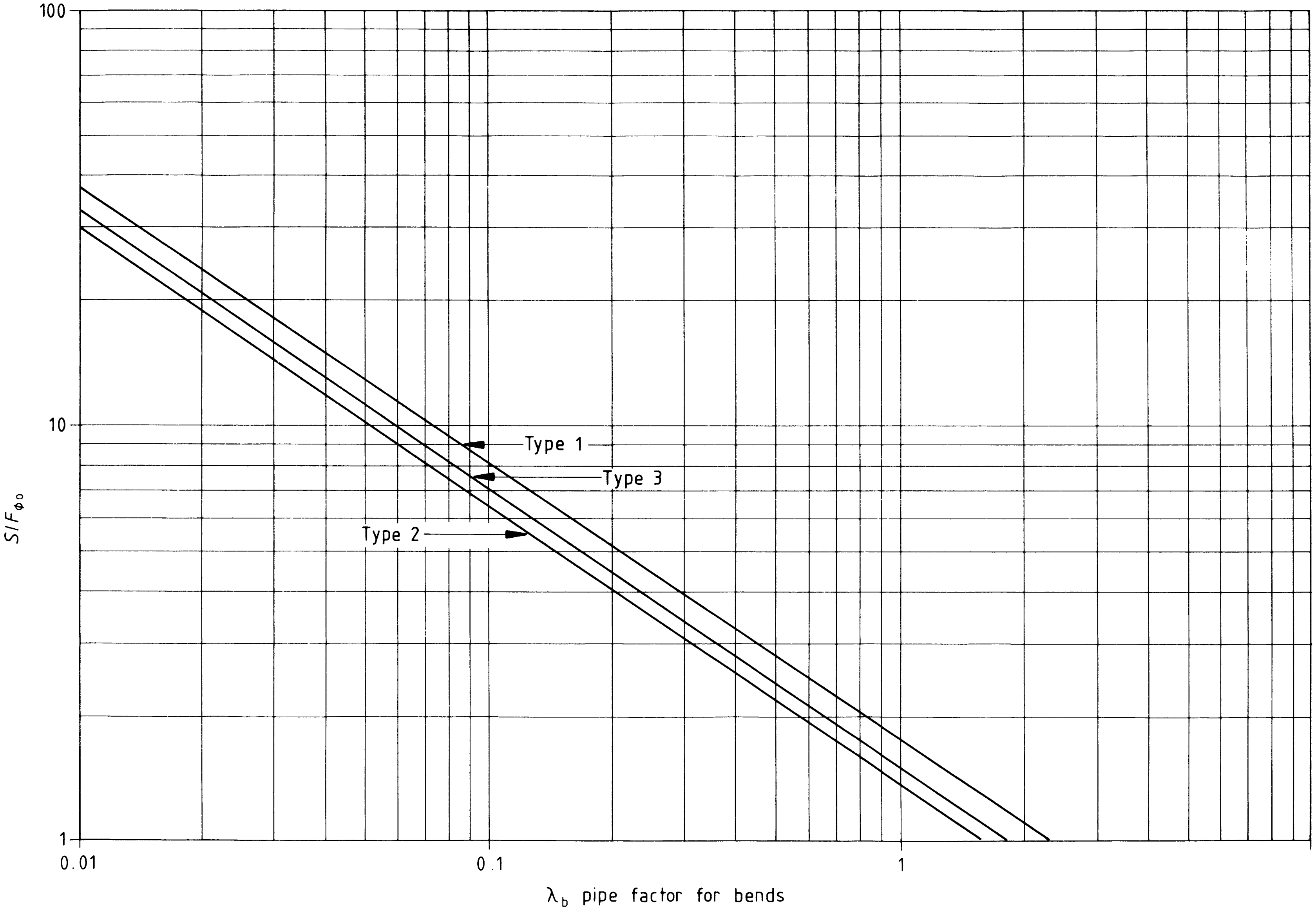


Figure 7.11 — Out-of-plane circumferential SIFs for mitred bends

7.3.1.6 *Correction factors for internal pressure.* Large diameter pipes with a low pipe factor (large bore/thin wall) are affected by internal pressure. The pressure results in a reduction of the stress intensification factors. The correction factors δ_x for longitudinal stress and δ_ϕ for circumferential stress can be calculated using the following equations (which are reproduced for convenience in Figure 7.1).

$$\delta_x = (1 + 2.53\epsilon_d R^{1/3} r t_d^{-4/3})^{-1} \quad (7.10)$$

$$\delta_\phi = (1 + 1.1\,\epsilon_d R^{2/3}\, r^{5/6} t_d^{-3/2})^{-1} \quad (7.11)$$

where the other terms correspond to those used for equation (7.7).

7.3.1.7 *Pressure stress multipliers for bends.* For mitred bends, the applicable pressure stress multiplier, m, is 1.3.

For smooth bends, the applicable pressure stress multiplier is

either 1.0or 0.83 $\left(1 - \frac{r}{2R}\right) \Big/ \left(1 - \frac{r}{R}\right)$,whichever is the greater, where r is the pipe bore radius, in millimetres, and R is the mean pipe bend radius, in millimetres.

7.3.2 Factors for tees

7.3.2.1 *Flexibility factors for tees.* In all cases, i.e. equal or unequal, moulded or fabricated, the flexibility factors for tees should be taken as 1, as indicated in Figure 7.12.

7.3.2.2 *Stress intensification factors for tees.* The stress intensification factor is non-directional and is primarily a function of the pipe factor and can be obtained graphically from Figure 7.13 or from the following equation:

$$SIF_T = \alpha_3 \lambda_T^{y3} \quad (7.12)$$

where

λ_T is the pipe factor applicable to the tee;

SIF_T is the stress intensification factor;

α_3 and y_3 are experimentally determined coefficients and powers which for both equal and unequal tees (see Figure 7.12) may be taken as 0.66 and – 0.5 respectively.

For this purpose, the pipe factor for tees λ_T is obtained from

$$\lambda_T = 2t_M/D_i \quad (7.13)$$

where

t_M is the thickness (in mm) of the reference laminate(s) of the main of the tee as shown in Figure 7.12 and, as applicable, Figure 7.14 or Figure 7.15;

D_i is the internal diameter of the main body of the tee (see Figure 7.12) (in mm).

For moulded tees where the crotch thickness is nominally 1.5 times that of the body of the tee as indicated in Figure 7.14 and Figure 7.15 the values given for α_3 and y_3 for equation (7.12) and in Figure 7.12 apply.

For set-on or set-in tees where the crotch thickness is nominally 2.5 times that of the body the values given for equation (7.12) and in Figure 7.12 will produce a conservative value of stress intensification factor.

7.3.2.3 *Pressure stress multiplier for tees.* Circumferential pressure stress $\sigma_{\phi p}$ at a tee junction is obtained from the following equation:

$$\sigma_{\phi p} = mp\,(D_{iM} + t_M)/20t_M \quad (7.14)$$

where

D_{iM} is the internal diameter of main of tee (in mm);

t_M is the thickness (in mm) of the reference laminate(s) of the main of the tee as shown in Figure 7.12 and, as applicable, Figure 7.14 or Figure 7.15;

p is the internal pressure (gauge) (in bar);

m is the pressure stress multiplier [see equation (7.15) and Figure 7.12 and Figure 7.16].

The value of the pressure stress multiplier can be obtained from the following equation:

$$m = \alpha_4 \lambda_Z^{y4} \quad (7.15)$$

where

α_4 and y_4 are experimentally determined coefficients and powers which for both equal and unequal tees (see Figure 7.12) may be taken as 1.4 and 0.25 respectively;

λ_z is the pipe factor applicable to the tee. For an equal tee it is obtained using equation (7.16) and for an unequal tee it is obtained using equation (7.17) (both of which are reproduced for convenience in Figure 7.12).

$$\lambda_Z = \frac{D_i}{2t_M} \quad (7.16)$$

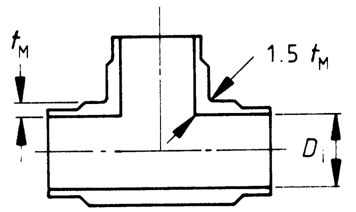
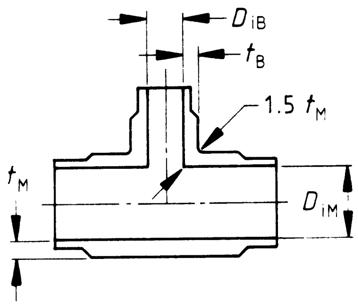
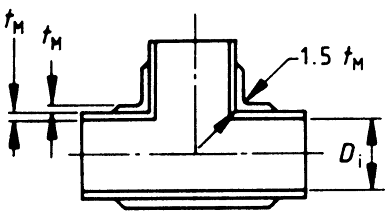
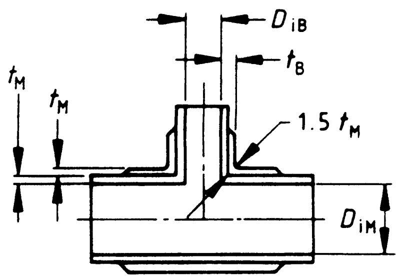
$$\lambda_Z = \left(\frac{D_{iB}}{2t_B}\right)^2\left(\frac{2t_M}{D_{iM}}\right) \qquad (7.17)$$

where

- D_{iB} is the internal diameter of the branch (in mm);
- t_B is the wall thickness of the branch adjacent to the junction (see Figure 7.12) (in mm);
- t_M is the thickness (in mm) of the reference laminate(s) of the main of the tee as shown in Figure 7.12 and, as applicable, Figure 7.14 or Figure 7.15;
- D_{iM} is the internal diameter of main of tee (see Figure 7.12) (in mm).

For set-on or set-in tees where the crotch thickness is nominally 2.5 times that of the body, the coefficient α_4 and the power y_4 will produce a conservative value of stress intensification factor.

Thermoplastics-lined tees can be considered as unlined.

Tees	Equal	Unequal
Moulded		
Fabricated (set-on or set-in)		
Flexibility factor	1.0	
Stress intensification factor (see **7.3.2.2**)	$SIF_T = 0.66\lambda_T^{-0.5}$ (7.12)[a]	
Pipe factor	$\lambda_T = \dfrac{2t_M}{D_i}$ (7.13)[a]	
Pressure stress multiplier	$m = 1.4\lambda_z^{0.25}$ (7.15)[a]	
Pipe factor	$\lambda_Z = \dfrac{D_i}{2t_M}$ (7.16)[a]	$\lambda_Z = \left(\dfrac{D_{iB}}{2t_B}\right)^2 \times \left(\dfrac{2t_M}{D_{iM}}\right)$ (7.17)[a]

[a] Indicates equation reference.

Figure 7.12 — Types of tees and associated factors

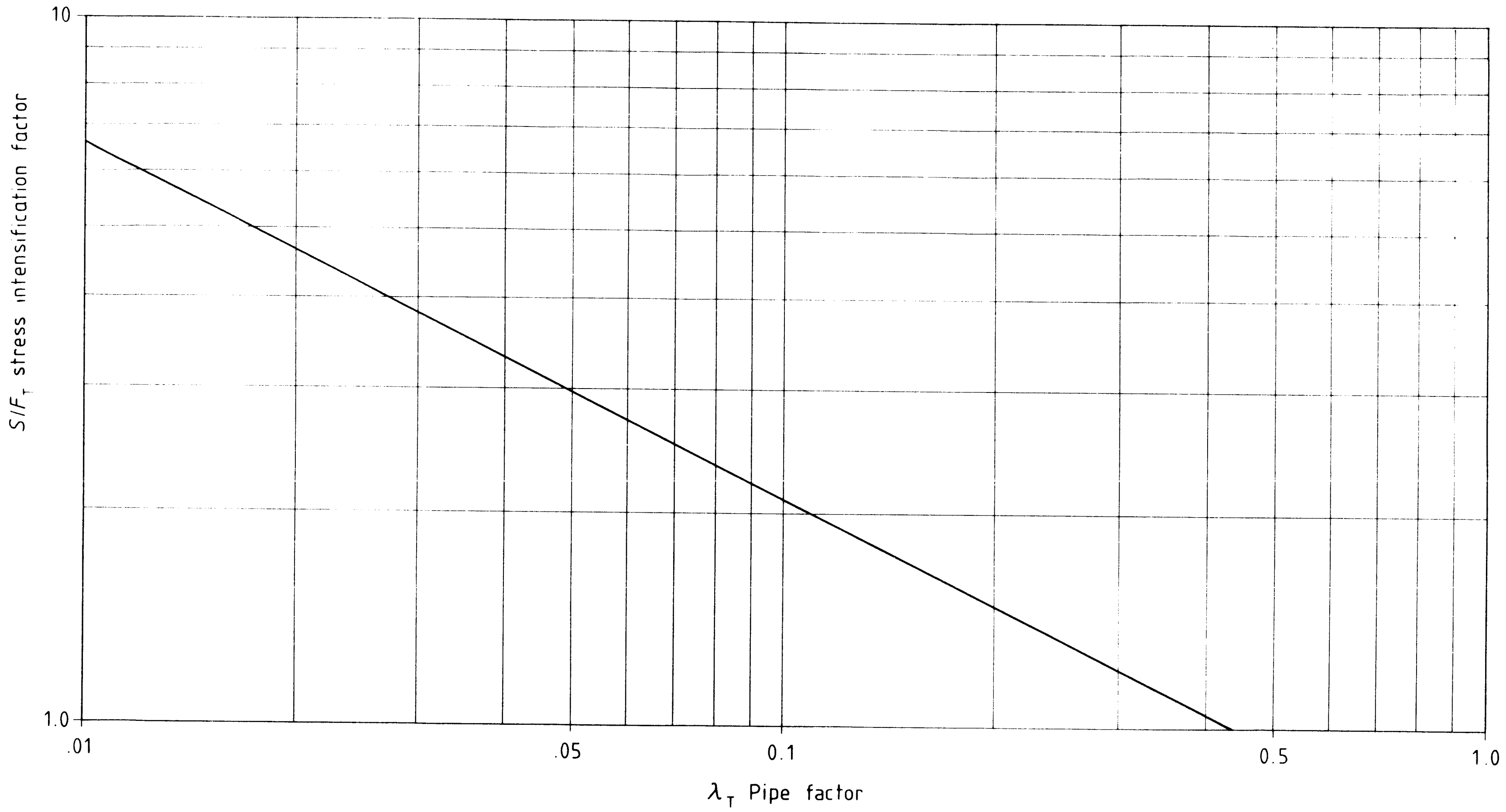
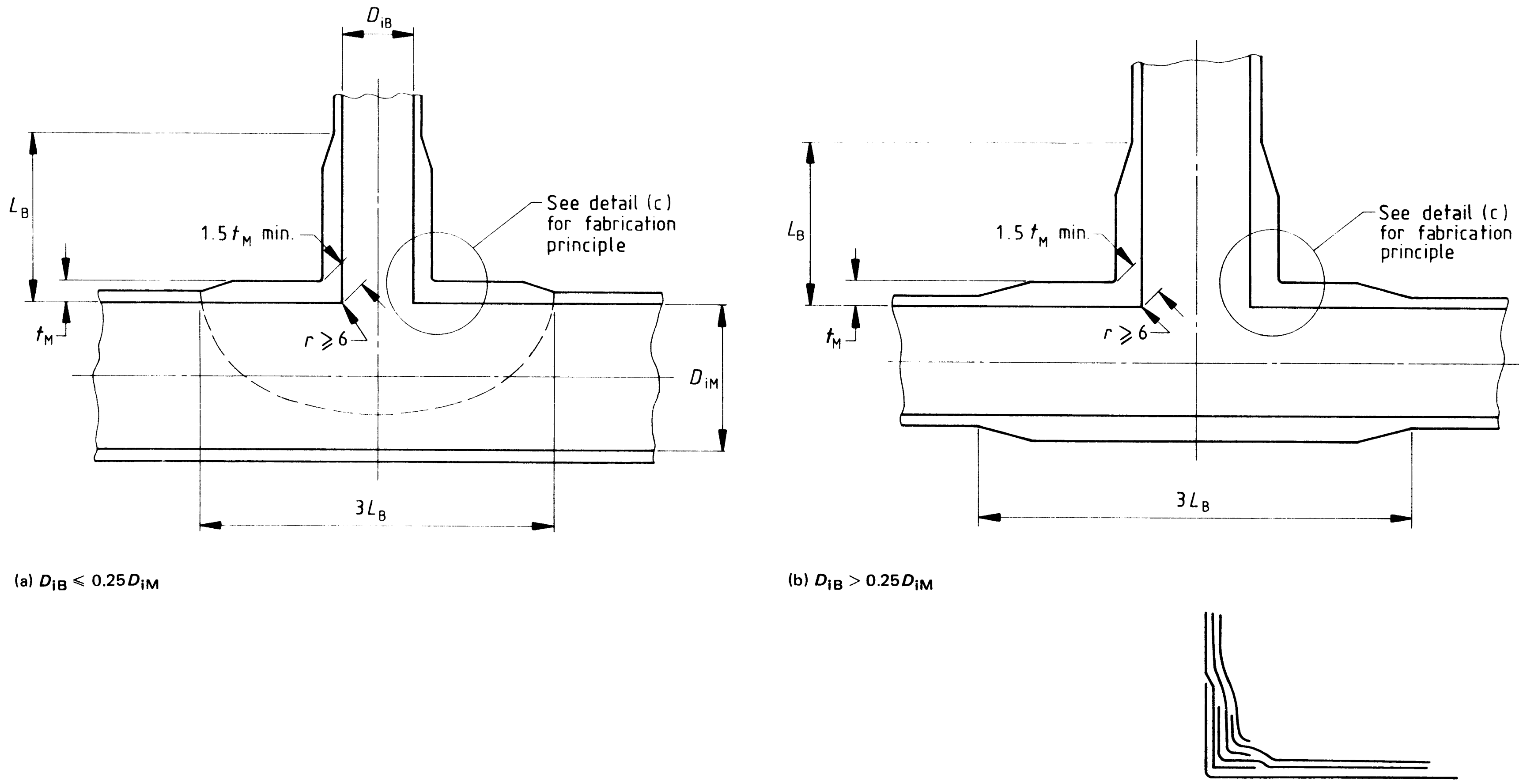


Figure 7.13 — Stress intensification factors for tees

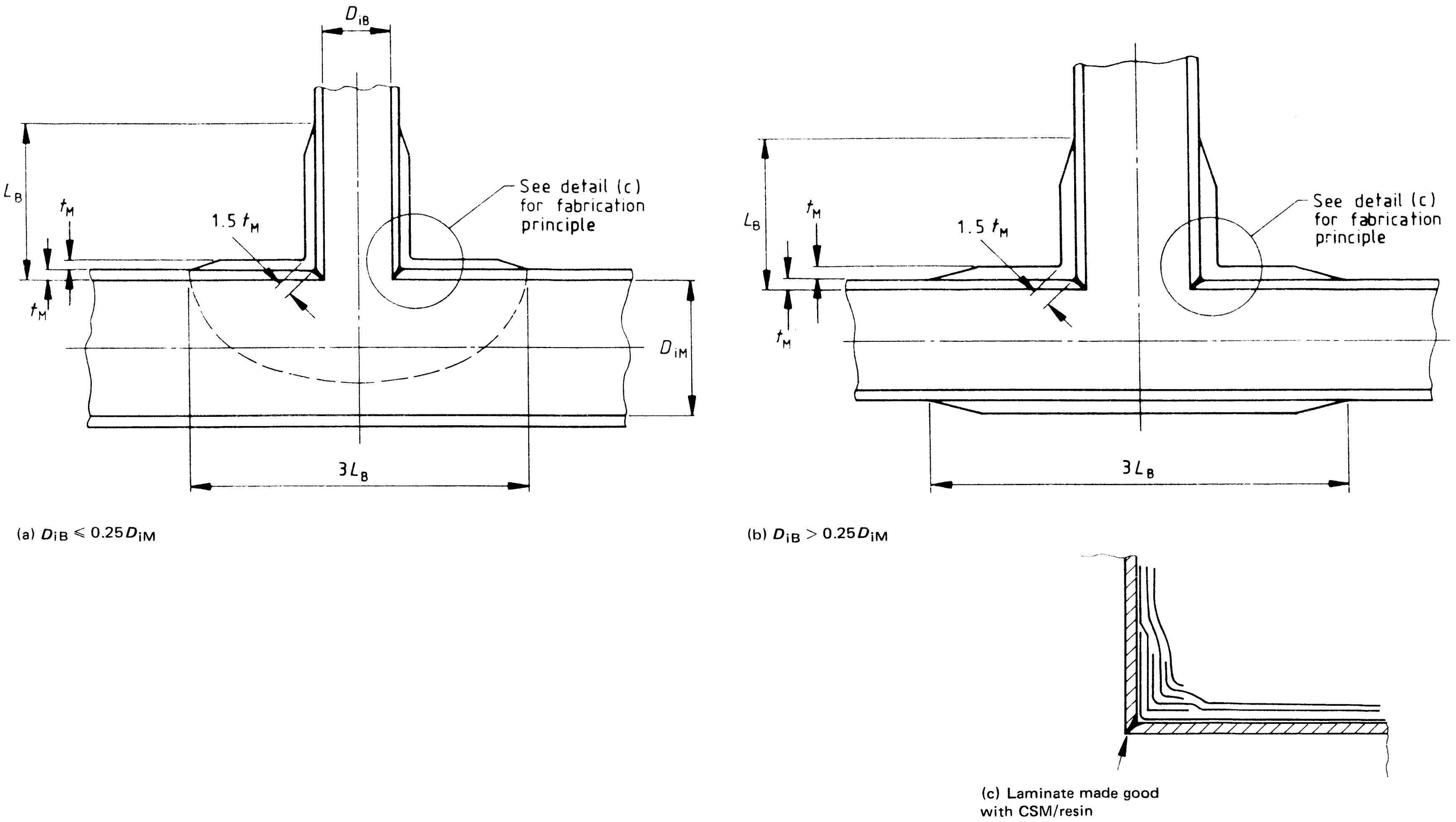


(c) Fabrication principle showing details of arrangement of glass layers

NOTE $L_B \geqslant D_{iB}$

Dimensions are in millimetres.

Figure 7.14 — Details of moulded tees



NOTE $L_B \geqslant D_{iB}$

Figure 7.15 — Details of set-on or set-in tees

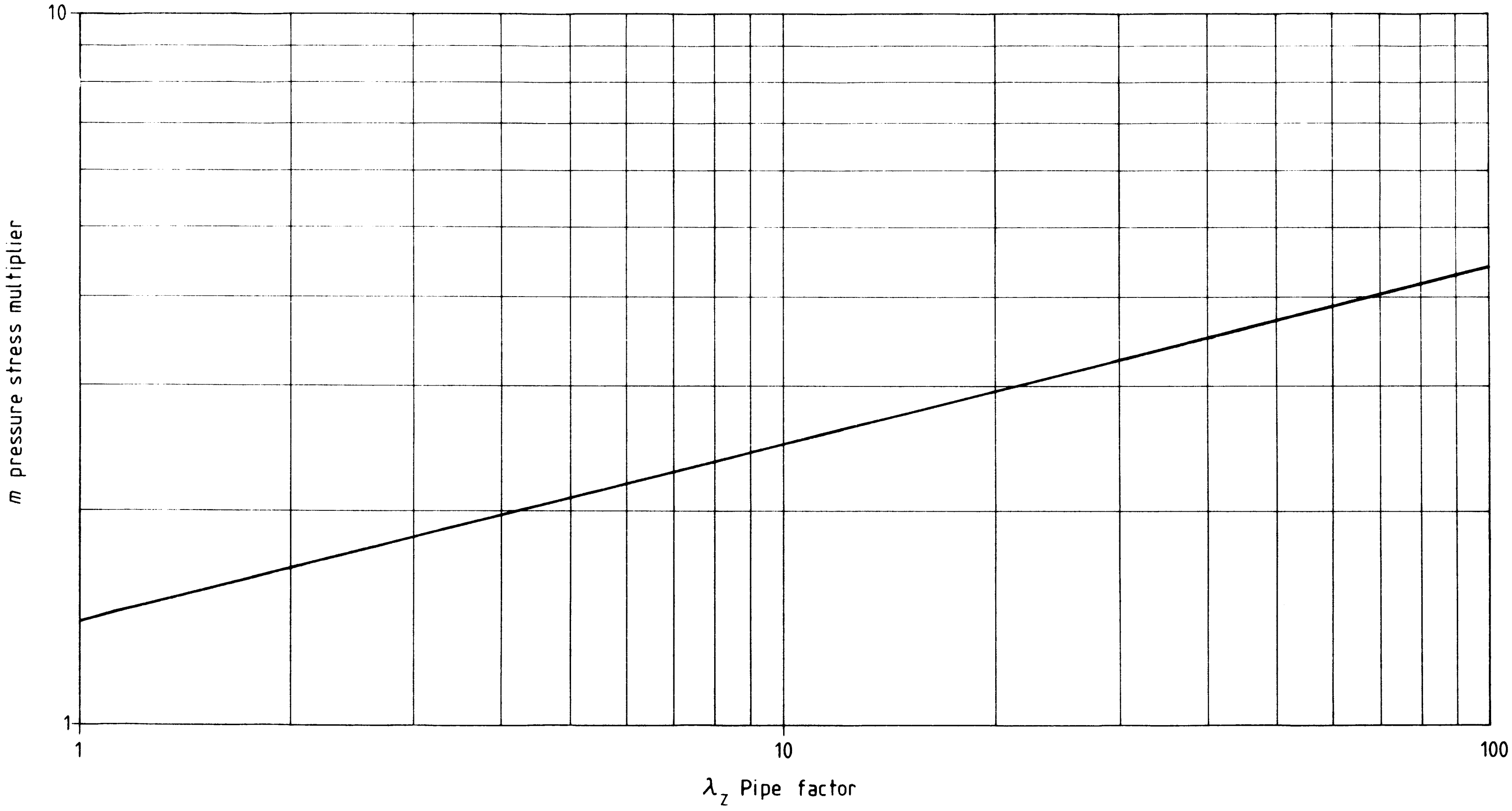


Figure 7.16 — Pressure stress multipliers for tees

7.3.3 Calculation of maximum combined stress

7.3.3.1 *General*. The calculation of the maximum combined stress should consider:

a) pressure-induced stresses;

b) bending stress induced by expansion or contraction over the total design temperature range;

c) bending stresses caused by the weight of pipe and, where applicable, insulation and pipe contents;

d) bending stresses caused by external loadings including wind;

e) bending stresses arising from movement of anchors, guides, supports or similar.

7.3.3.2 *Maximum combined stress*. The maximum combined stress should not exceed the maximum design stress for the laminate at any location.

7.3.3.3 *Combined stress: straights and bends*. The combined stress value on straights and bends should be the maximum value obtained from the following equations;

$$\sigma_c = (\sigma_\phi^2 + 4\sigma_S^2)^{0.5} \quad (7.18)$$

or

$$\sigma_c = (\sigma_x^2 + 4\sigma_S^2)^{0.5} \quad (7.19)$$

where

σ_c is the combined stress (in MPa);

σ_ϕ is the circumferential stress (in MPa);

σ_x is the longitudinal stress (in MPa);

σ_S is the torsional stress (in MPa).

7.3.4 Stress equations: straights and bends

7.3.4.1 *Circumferential stress*. The total circumferential stress σ_ϕ is the sum of the circumferential pressure stress $\sigma_{\phi p}$ and the circumferential bending stress $\sigma_{\phi b}$, i.e.

$$\sigma_\phi = \sigma_{\phi p} + \sigma_{\phi b} \quad (7.20)$$

where values for these circumferential stresses may be obtained as follows.

a) *Circumferential pressure stress*

$$\sigma_{\phi p} = mp\,(D_i + t_d)/20t_d \quad (7.21)$$

where

m is the pressure stress multiplier for a straight pipe (= 1) or a bend as applicable (see **7.3.1.7** and Figure 7.1);

p is the internal pressure (gauge) (in bar);

D_i is the internal diameter (in mm);

t_d is the design thickness of the reference laminate (in mm).

b) *Circumferential bending stress*

For straight pipes, $\sigma_{\phi b}$ should be taken as zero.

For bends:

$$\sigma_{\phi b} = \{(D_i + 2t_d)/2I\}\,\{(M_i SIF_{\phi i})^2 + (M_o SIF_{\phi o})^2\}^{0.5} \quad (7.22)$$

where

M_i is the maximum in-plane bending moment (in N·mm);

M_o is the maximum out-of-plane bending moment (in N·mm);

$SIF_{\phi i}$ is the circumferential stress intensification factor, in-plane (see **7.3.1.4** and Figure 7.1);

$SIF_{\phi o}$ is the circumferential stress intensification factor, out-of-plane (see **7.3.1.4** and Figure 7.1);

I is the second moment of area about an axis through the centroid normal to the axis of the pipe (in mm^4);

D_i is the internal diameter of the fitting (in mm);

t_d is the design thickness of the reference laminate (in mm).

7.3.4.2 *Longitudinal stress*. The total longitudinal stress σ_x is the sum of the longitudinal pressure stress σ_{xp} and the longitudinal bending stress, σ_{xb}, i.e.

$$\sigma_x = \sigma_{xp} + \sigma_{xb} \quad (7.23)$$

where values for these longitudinal stresses may be obtained as follows:

a) *Longitudinal pressure stresses* σ_{xp}

This may be calculated for both straight pipes and bends from the equation

$$\sigma_{xp} = p(D_i + t_d)/40t_d \quad (7.24)$$

b) *Longitudinal bending stress*

1) For straight pipe

$$\sigma_{xb} = \{(D_i + 2t_d)/2I\}\,(M_i^2 + M_o^2)^{0.5} \quad (7.25)$$

2) For bends

$$\sigma_{xb} = \{(D_i + 2t_d)/2I\} \{(M_i SIF_{xi})^2 + (M_o SIF_{xo})^2\}^{0.5} \quad (7.26)$$

where for equations (7.24), (7.25) and (7.26) (as applicable)

- p is the internal design pressure (gauge) (in bar);
- D_i is the internal diameter (in mm);
- t_d is the design thickness of the reference laminate (in mm);
- I is the second moment of area about an axis through the centroid normal to the axis of the pipe (in mm^4);
- M_i is the maximum in-plane bending moment (in N·mm);
- M_o is the maximum out-of-plane bending moment (in N·mm);
- SIF_{xi} is the longitudinal stress intensification factor under in-plane bending (see **7.3.1.4** and Figure 7.1);
- SIF_{xo} is the longitudinal stress intensification factor under out-of-plane bending (see **7.3.1.4** and Figure 7.1).

7.3.4.3 *Torsional stress*. For both straights and bends the torsional stress σ_S (in MPa) is given by:

$$\sigma_S = M_S (D_i + 2t_d)/4I \quad (7.27)$$

where

- M_S is the maximum torsional moment (in N·mm);
- D_i is the internal diameter (in mm);
- t_d is the design thickness of the reference laminate (in mm);
- I is the second moment of area about an axis through the centroid normal to the axis of the pipes (in mm^4).

7.3.5 Combined stress: branch connections

The combined stress at a branch junction should be determined from the following equation:

$$\sigma_{cB} = \{(\sigma_{\phi p} + \sigma_{bB})^2 + 4\,\sigma_{SB}^2\}^{0.5} \quad (7.28)$$

where

- σ_{cB} is the branch combined stress (in MPa);
- $\sigma_{\phi p}$ is the branch circumferential pressure stress (in MPa);
- σ_{bB} is the non-directional bending stress (in MPa);
- σ_{SB} is the branch torsional stress (in MPa).

7.3.6 Stress functions: branch connections

7.3.6.1 *Circumferential pressure stress*. The circumferential pressure stress $\sigma_{\phi p}$ should be determined from the following equation:

$$\sigma_{\phi p} = mp\,(D_i + t_M)/20t_M \quad (7.29)$$

where

- m is the pressure stress multiplier [see equation (7.15) and Figure 7.12 and Figure 7.16];
- p is the internal pressure (gauge) (in bar);
- D_i is the internal diameter of main bore at junction of branch (in mm);
- t_M is the minimum thickness of the reference laminate(s) of the main at the branch connection (see Figure 7.14 and Figure 7.15).

7.3.6.2 *Non-directional bending stress*. The non-directional bending stress at branch junctions should be the greatest value applicable to each of the three connections determined as follows:

a) the bending stress at branch from connection on main, σ_{bB}, as given by the equation:

$$\sigma_{bB} = \{(D_i + 2t_d)/2I\} \{(M_i\,SIF_{Bi})^2 + (M_o\,SIF_{Bo})^2\}^{0.5} \quad (7.30)$$

where

- M_i is the in-plane moment: either main according to case (in N·mm);
- M_o is the out-of-plane moment: either main according to case (in N·mm);
- SIF_{Bi} is the in-plane branch stress intensification factor;
- SIF_{Bo} is the out-of-plane branch stress intensification factor;
- D_i is the internal diameter of main bore at junction of branch (in mm);
- I is the second moment of area of the main about an axis through the centroid normal to the axis of the main (in mm^4);
- t_d is the design thickness of the reference laminate (in mm).

b) The bending stress at the branch junction from the branch connection should be determined as for the main connections but with the in- and out-of-plane moments being those applicable to the branch connection. The radius should be that of the branch. The moment of inertia should be that calculated using the branch radius and the lesser of the main thickness or branch thickness multiplied by the out-of-plane stress intensification factor of the branch.

c) The torsional stress at the branch junction should be the value applicable at any connection, where the torsional stress is as defined for straight and bends in **7.3.4.3**.

7.4 Accommodation of expansion as longitudinal compressive strain

Because of the low elastic modulus of GRP it is possible to deal with thermal expansion in a way which is not often practicable with metallic pipe systems. If a straight length of GRP pipe is restrained between anchors it can be heated (within limits) with expansion prevented by the anchors, i.e. the expansion which would take place if the pipe were free to expand is absorbed as an axial strain. A pipe run treated in this way is usually referred to as a restrained pipe system.

Significant features of this method are:

a) The method is best suited to pipelines which incorporate relatively long straight runs.

b) The method is more generally used for smaller sizes of pipe because of the high anchor loads generated by larger pipes. As an example a 150 mm nominal bore GRP pipe with a 10 mm thick wall would generate an anchor load of about 50 kN for a temperature difference of 60 K.

c) The pipe supports between the anchors have to prevent the pipe buckling as a strut. Cradle type supports with overstraps are often used. The supports should be rigidly attached to the plant steelwork or other supporting structures. Hangers are not satisfactory because they do not prevent lateral movement of the pipe.

d) Those parts of the pipe run which are not fully restrained should be considered separately from a flexibility viewpoint and, if necessary, analysed by the methods given in **7.3**.

e) Compressive stress induced by a temperature rise can decay through relaxation of the pipe material and, on cooling, tensile stress can be generated. The total tensile stress will be much greater if the pipe is allowed to cool under pressure because of the axial tensile stress arising from the Poisson effect. Unless otherwise stated, the anchor should be capable of resisting equal and opposite loads in the axial direction. Ignoring deflection in response to end thrust the anchor load f_N is given by:

$$f_N = E_{LAM} \, \Delta \, T_d \, \alpha_\ell \{t_d \pi \, (D_i + t_d)\} \quad (7.31)$$

where

f_N is the anchor load (in N);

E_{LAM} is the elastic modulus of the laminate (in MPa);

T_d is the design temperature change (in K);

α_ℓ is the linear thermal expansion coefficient;

t_d is the laminate thickness (in mm);

D_i is the internal diameter (in mm).

f) The longitudinal compressive stress induced by the temperature rise will result in a circumferential tensile strain, because of the Poisson ratio effect. The sum of this strain and the circumferential strain induced by pressure should not exceed the design strain. Where σ_x is negative, the circumferential strain should be calculated for type 1 and type 2 laminates using equation (7.32) or for type 3 laminates using equation (7.33).

$$\epsilon_\phi = (\sigma_\phi - \nu_{\sigma x})/E_{LAM\phi} \quad (7.32)$$

$$\epsilon_\phi = (\sigma_\phi - \nu_{\phi x} \, \sigma_x) \, E_{LAM\phi} \quad (7.33)$$

where

ϵ_ϕ is the design strain;

σ_ϕ is the circumferential stress (in MPa);

ν is the Poisson ratio;

σ_x is the longitudinal stress (in MPa);

$E_{LAM\phi}$ is the modulus of elasticity of the reference laminate in the circumferential direction;

$\nu_{\phi x}$ is the Poisson ratio giving strain in the longitudinal direction caused by stress in the circumferential direction assuming a balanced construction.

NOTE $\nu_{x\text{Ã}}/E_{\text{LAM x}} = \nu_{\phi x}/E_{\text{LAM Ã}}$

where

$\nu_{x\text{Ã}}$ is the Poisson ratio giving strain in the circumferential direction caused by stress in the longitudinal direction assuming a balanced construction;

$E_{\text{LAM x}}$ is the modulus of elasticity of the reference laminate in the longitudinal direction (in MPa).

g) The longitudinal strain increases with the expansion temperature range. Calculation of the maximum strain should be included for:

1) thermal expansion;

2) the mass of the pipe and its contents;

3) any initial curvature of the pipe as fabricated. The curvature should be assumed to be downward.

For unlined GRP pipework the allowable compressive strain can be taken as 1.25 times the allowable strain from section 4.

h) On a restrained pipe run the anchoring of the pipe should be the last operation to be carried out. This is particularly so if the site joints are overwrapped butt joints; if the anchors are fixed before jointing any forces or moments arising from temperature changes during the curing of the resin may prevent sound joints being made.

i) Anchors should be capable of resisting both tensile and compressive forces. Consideration should be given to procedures to be used during any modifications or repair.

Section 8. General layout considerations

8.1 Thermal effects

Because of the high coefficient of expansion, thermal expansion and contraction almost always influences the choice of route and/or method of supporting. Thermal effects should be considered at an early stage in design.

8.2 Site joints

As with carbon steel, properly made site butt joints are less likely to leak in service than flanged joints. Site butt joints have the additional advantages that lengths and alignments of fabricated pieces can be adjusted on site if the pieces are delivered to site over length. Wherever possible site joints should be positioned in accessible positions away from supports and fittings. The positions of joints may be dictated in part by the dimensions of fittings and the relative positions of branches. Nominal dimensions considered suitable for GRP fittings are given in Appendix D.

8.3 Isolation

Isolation for maintenance purposes can conveniently be carried out by the removal of a flanged bend followed by blanking off. If this is not possible and isolation is to be achieved by the insertion of a slip plate in a flanged joint, it should be borne in mind that the joint should not be parted by driving in wedges because this will damage the flanges.

The joint to be used for isolation should be shown at the design stage and should be in a position where the flange can in practice be jacked apart, e.g. it should not be in a straight run of pipe between two anchors. If frequent isolation for maintenance is necessary, consideration should be given to the provision of a slip ring and jacking rings. The jacking rings, if used, should be moulded integrally with the pipe ends during fabrication. Isolation is carried out by:

a) removing the flange bolts;

b) placing the backing flanges against the jacking rings and forcing them apart using screwed rods and nuts;

c) replacing the slip ring by a slip plate, releasing the backing flanges and bolting the joint up.

8.4 Heat tracing

Heat tracers should be spirally wound on to GRP pipe in order to distribute the heat evenly round the pipe wall. Electrical tracing is generally more convenient but care should be taken that the tracers are not wound too tightly on to the pipework or they may be damaged when the pipe expands.

If steam tracing is used the tracer pipe should not come into contact with the GRP.

8.5 Nearby pipes

Possible leakage or other effects from nearby pipes should be considered, e.g. a GRP pipe should not be run alongside a steam main with flanged joints; a jet of steam from a flange leak can soon cause a GRP pipe to fail.

8.6 Vulnerability

GRP pipework should not be run in vulnerable positions, e.g. where it can be hit by maintenance trucks or other vehicles. Small branches can also be vulnerable, e.g. a small branch carrying a bleed valve for a block-and-bleed system can easily be damaged.

The resins used for GRP are generally inflammable. It is recommended that at least the outside layer of the pipe contains a fire retardant chemical to prevent flame spread, but even so the pipe is likely to be damaged by fire.

If GRP is used for air ducting the inside layer should also be fire retardant, to prevent the spread of flame down the duct. It is best, in practice, to specify fire retardant resin for the whole of the pipe wall laminate.

8.7 Transient vacuum conditions

Pipework systems should be checked for possible transient low pressure conditions. Flow conditions which would not harm a steel pipe can collapse a GRP pipe if it has not been constructed to resist vacuum. For example in a long vertical pipe carrying liquid from an elevated vessel to a lower level, if an isolating valve near the vessel is suddenly closed, the momentum of the flowing liquid could cause a partial vacuum.

8.8 Vibration

Vibration of a pipeline, even if it does not overstress the main run, can cause damage in two ways.

a) The pipe can be damaged by chafing in supports.

b) Branch lines can be overstressed.

Possible vibrations arising from, for example, pressure pulses, falling columns of liquid or wind effects should be considered during design. The pipework should also be checked for vibration during commissioning and additional supports or braces may be fitted if necessary and where acceptable to the design.

8.9 Fabrications

The pipework should be designed so that as much of the fabrication as possible can be done in the workshop. Appendix D gives dimensional design details of fittings. Fittings having nominal dimensions in accordance with Table D.1 should be used unless it is essential (e.g. because of space limitations) to make use of fittings in accordance with Table D.2.

Fabrication by hand methods means that quality can vary. Rigorous inspection and supervision is necessary in the workshop and on site to ensure sound and reliable pipework.

8.10 Conduction of electricity

GRP is a poor conductor of electricity; hence:

a) GRP pipes do not conduct stray currents

b) Static charges can build up on the pipe surface unless action is taken to reduce the resistivity of the laminate, e.g. by including conductive fillers.

8.11 Conduction of heat

GRP is a poor conductor of heat, which has the following consequences.

a) The rate of conduction of heat through the pipe in a plant fire will be much less than for metallic pipes. A GRP pipe may survive and contain the fluid for longer than a metallic one, especially if the laminate has a fire retardant surface.

b) There is less need to insulate hot pipes and rarely any need to insulate for personnel protection.

8.12 Relationship between circumferential and longitudinal properties of straight pipe lengths

The longitudinal stress due to pressure is up to half the circumferential stress depending on the loading. Hence if internal pressure were the only consideration, it would be sensible for the pipe wall laminate to have values of unit modulus and UTS in the circumferential direction twice those in the longitudinal direction.

In practice for process pipework which is intermittently supported and subject to temperature changes, there will be bending loads causing longitudinal tensile stresses on one side of the pipe and compressive stresses on the other side. The tensile stresses will be additive to the longitudinal stress arising from internal pressure. To provide for this additional longitudinal tensile stress it is normal practice to make the longitudinal unit modulus and ultimate tensile unit strength (u_x) of the pipe wall similar to the circumferential modulus and ultimate tensile unit strength (u_ϕ).

For anisotropic pipes full consideration of the loading is required to determine the most efficient winding angle.

Note that any external pressure (or vacuum) requires special consideration (see section 6).

Section 9. Pipe supports and anchorages

9.1 General

Wherever possible the design of supports, anchors and secondary steelwork should be in accordance with BS 3974-1 and BS 3974-2.

The outside diameter of a particular pipe should be determined from the manufacturer before ordering brackets. Where the support makes use of clamps a rubber insert should be positioned between the pipe and clamp. The internal diameter of the clamp should allow for the thickness of the insert.

BS 3974 is based on steel practice. The following sections of BS 3974 should only be used for GRP pipe after considering the following exceptions:

BS 3974-1

a) section 5: applicable, except that U bolts and hooks should not be used;

b) section 6: not applicable to GRP pipework;

c) section 7: not applicable to GRP pipework when the pipe rests on a roller;

d) Table 13 to Table 16: not applicable.

BS 3974-2

a) section 9: with GRP pipework, build up instead of using support lugs;

b) section 10: with GRP pipework, duckfoot support should be tubular only. Table 11(a) is not applicable. The duckfoot should be 150 mm diameter or the pipe diameter, whichever is the lesser.

9.2 Allowable loadings

9.2.1 Pipes made of type 1 or type 2 laminates

(see Table 4.2)

It is recommended that only 25 % of the allowable longitudinal tensile loading be used for supporting the pipe (leaving 50 % for pressure containment and the remaining 25 % for thermal effects).

In no case should the maximum compressive unit loading $Q_{C\,max}$ exceed the value given by the following equation:

$$Q_{C\,max} = t_d\,\sigma_{Cd} = 0.58\,t_d\,X_{LAM}/D_iF_s \quad (9.1)$$

where

$Q_{C\,max}$ is the maximum compressive unit loading (in N/mm);

σ_{Cd} is the design compressive stress (in MPa);

t_d is the design thickness of the reference laminate (in mm);

X_{LAM} is the laminate unit modulus (in N/mm);

D_i is the inside diameter (in mm);

F_s is the safety factor, which should take the value 4 unless otherwise agreed.

9.2.2 Pipes made of type 3 laminates

(see Table 4.2)

The construction of type 3 pipes is anisotropic. Therefore the support of type 3 pipes needs special consideration because a nominal increase in longitudinal loading could lead to premature circumferential failure.

9.3 Allowable deflection

For all three types of pipes the deflection should be limited to 1/300 of the span between supports.

9.4 Loading conditions

The support spans should be checked for combinations of the following loads.

a) Uniformly distributed toads:

1) mass of pipework;

2) contents of pipework;

3) lagging on pipework;

4) wind loads on pipework.

b) Concentrated loads comprising:

1) permanent point loads;

2) temporary point loads, such as the force exerted by a load (person) of 100 kg minimum at mid-span on any pipe of more than 100 mm nominal diameter.

9.5 Support span calculations

9.5.1 Simply supported

Piping systems supported on hangars should be considered to be simply supported. The span should be limited to produce deflections not exceeding 1/300 of the span. The length of the span may be calculated from the following equations.

a) Uniformly distributed load:

$$L = (E_{LAM}\,D_i^3\,t_d/10W)^{0.33} \quad (9.2)$$

b) Concentrated toad:

$$L = (E_{LAM}t_dD_i^3/16P)^{0.5} \quad (9.3)$$

where

L is the length of span (in mm);

D_i is the internal diameter of the pipe (in mm);

W is the distributed load (suffix w for wind load) (in N/mm);

P is the point load (in N);

E_{LAM} is the modulus of elasticity of the laminate (in MPa);

t_d is the laminate wall thickness (in mm);

9.5.2 Encastré

The system can be considered encastré when anchored. The length of the span can be calculated as follows.

a) Uniformly distributed load:

$$L = (E_{LAM}\, D_i^3 t_d / 2W)^{0.33} \qquad (9.4)$$

b) Concentrated load:

$$L = (E_{LAM}\, D_i^3\, t_d / 4P)^{0.5} \qquad (9.5)$$

9.6 Wind loads

Wind loading should be taken as a distributed load calculated in accordance with CP 3:Chapter V-2.

Section 10. Methods of jointing

10.1 General requirements for laminated joints

10.1.1 Strength

The strength of all joints, particularly circumferential, longitudinal, flexural and torsional strengths, should be not less than that of the pipework.

When tested in accordance with BS 5350-C5, using double overlapped joint test pieces, the lap shear strength should not be less than 7 MPa[4] for epoxide and polyester resin based joints and 5 MPa[4] for furane resin based joints.

10.1.2 Surface preparation

Prior to jointing, pipes and fittings should be abraded to remove the resin-rich surface and expose the glass fibres over an area extending at least 25 mm beyond the joint overlay. It is essential to prohibit the use of paraffin wax in this area.

10.1.3 Jigs

A jig or other equivalent device should be employed to ensure that the pipes are maintained with the joint faces held rigidly in relation to each other. The restraints should be left in place until the joint has adequate mechanical strength such as would be attained one hour after gelation of the resin or when the surface hardness meets any applicable requirements.

10.1.4 Internal step

The bores of adjacent pipes for jointing should be such that the internal step on completion of the butt joint should not exceed the applicable value given in Table 10.1.

Table 10.1 — Internal step

Pipe nominal size	Maximum internal step	
	Unlined	Thermoplastics lined
	mm	mm
Up to and including 200 mm	2	1
Above 200 mm to below 450 mm	3	1
450 mm and above	4	1

10.1.5 Overlay

The minimum values for overlay lengths for reference laminates are given in Table 10.2 (see note).

Table 10.2 — Overlay lengths for butt joints

Pipe laminate no. (see Table 5.1)	Minimum overlay length (L_{OVL})	
	Polyester and epoxide	Furane
	mm	mm
L25	150	200
L30	150	250
L40	200	300
L50	250	350
L60	300	400
L80	400	500
L100	500	650
L120	550	800
L140	650	900
L160	750	1 050
L180	850	1 150
L200	950	1 300
L225	1 050	1 450
L250	1 150	1 800
L275	1 250	1 800
L300	1 400	1 950
L350	1 600	2 250

The length of the first layer should be 50 mm minimum or equal to the length of the tapers and successive layers should increase uniformly in length to provide the minimum total width and thickness of overlay.

A minimum of 1.2 kg/m^2 of CSM should be applied initially. Woven roving cloth may be incorporated in subsequent layers alternating with CSM layers, but an outer layer of CSM and an outer resin rich layer should be provided.

The quantity of glass reinforcement used in the overlay should be such as to produce a design unit modulus of at least 1.25 times that of the pipe wall, except that this requirement does not apply to shop-fabricated fittings for which the applicable factor is $\geqslant 1$.

When jointing pipes of different wall thickness the requirements for overlay length and laminate should correspond to those of the thinner wall pipe.

[4] 1 MPa = 1 N/mm^2.

NOTE Subject to a minimum value of 150 mm, the values in Table 10.2 were derived using the equation

$L_{OVL} = 2F_s\epsilon_d X_{LAM}/S_s$

or $0.5D_i$, whichever is the greater,

where

L_{OVL} is the minimum overlay length (in mm);

F_s is the factor of safety, which should be related to the class of pipe (see **4.3.2.1** and Table 4.3) as follows:

Class	F_s
1	8
2	10
3	12
4	16

ϵ_d is the design strain;

X_{LAM} is the laminate unit modulus determined in the axial direction (in N/mm);

S_s is the lap shear strength (in MPa);

D_i is the internal diameter of the pipe or fitting (in mm).

10.1.6 Statement of detail of site joints

The manufacturer should provide full details of the procedures he proposes to follow when carrying out site joints. These details should include the numbers of layers and grammages and types of glass reinforcement to be used and details of jigs or other devices to be used.

10.1.7 Procedure validation

The manufacturer should provide evidence that the method he proposes for shop or site joints meets the recommendations of this code. This recommendation may be met by, for example, evidence of prior experience or tests on prototypes to the satisfaction of the inspecting engineer.

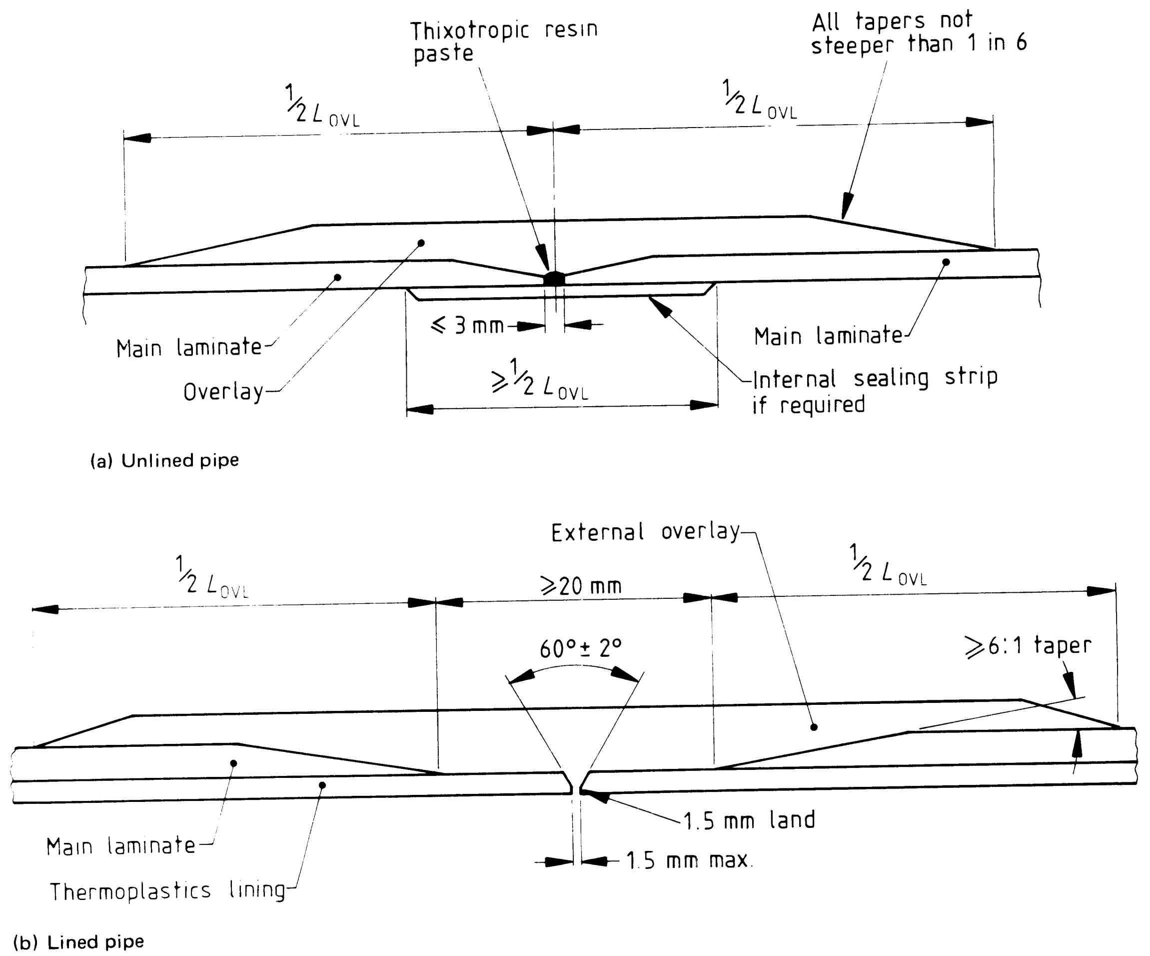


Figure 10.1 — Butt joints

10.2 Butt joints in unlined pipes

Butt joints should be fabricated in accordance with the detail shown in Figure 10.1, the ends of the pipe being chamfered back to a minimum taper of 1 in 6, to leave a root face square to the axis of the pipe and 2 mm to 3 mm thick. The pipe ends should be abraded then butted together and held rigidly in position with a maximum gap of 3 mm and the applicable tolerance on internal alignment.

The chamfered, abraded and cut surfaces should be coated with the specified resin and the gap between the ends filled with resin paste. After allowing the resin paste to set hard, any excess should be ground off such that the width of the paste layer is less than 10 mm. Where possible a spark test should then be applied to check for porosity. Any pin holes should be ground out and repasted. The glass fibre overlay should then be applied centred on the joint.

The interior of joints should, where accessible, be sealed with a minimum of 1.2 kg/m^2 of CSM and surface tissue layer. This internal layer should not be considered in meeting the unit modulus requirement.

10.3 Butt joints in lined pipes

Butt joints should be fabricated in accordance with the details shown in Figure 10.1.

The ends of the pipe should be prepared by cutting back the reinforcement for a sufficient distance, which should be not less than 10 mm, to ensure that no glass fibres are included in the thermoplastics weld. The reinforcement should be chamfered back at a minimum taper of 1 in 6 and the surfaces abraded.

The liner should be cut to produce a root face square to the axis of the pipe and the ends should be chamfered to an included angle of 60° and degreased. The pipe ends should be butted together and held rigidly in position with a maximum gap of 1.5 mm and the applicable tolerance on internal alignment.

The lining should be welded and the weld spark tested using a temporary earthing strip. After spark testing has shown that the weld in the thermoplastics lining is satisfactory, the reinforcement should be built up in successive layers centred on the weld. The recommendations given in **10.2** should be followed where applicable.

10.4 Spigot and socket joints in unlined pipes

Parallel or taper spigot and socket joints may be used. The socket may be formed as an integral part of the pipe or fitting or may be part of a socket coupling. Socket joints should meet the following limits.

a) For pipes based on polyester or epoxide resins, the depth of the socket should be equal to or greater than the applicable value given in Table 10.3, otherwise, for pipes based on furane resins, the value should be increased by a factor of 1.4.

NOTE Subject to a minimum value of 25 mm, the minimum socket depths given in Table 10.3 were derived using the following equation:

$$L_2 = F_s \epsilon_d X_{LAM}/S_s$$

where

L_2 is the socket depth (for cemented joint for pressure) (in mm);

F_s is the factor of safety, which should be related to the class of pipe (see **4.3.2.1** and Table 4.3) as follows:

Class	F_s
1	8
2	10
3	12
4	16

S_s is the lap shear strength (in MPa) for which a value of 7 has been assumed [see d)];

ϵ_d is the design strain;

X_{LAM} is the laminate unit modulus, determined in the axial direction (in N/mm).

b) The manufacturer should provide a cement compatible with the process conditions for which the pipe is intended.

c) The joint should be designed so that the thickness of the cement is between 0.15 mm and 1.5 mm.

d) The bond between the pipe, socket and cement should give a minimum strength of 7 MPa[5] when a type test is performed in accordance with the method described in BS 5350-C5 using double overlap joints as test pieces.

e) The manufacturer should state the minimum temperature and maximum humidity under which the bonding cement cures to provide a good joint. The manufacturer should provide precise details of the method of assembly and proof of its performance.

[5] 1 MPa = 1 N/mm^2.

f) If practicable the interior of the joints should be freshly abraded to remove glass and should be sealed with a laminate containing a minimum of 900 g/m² CSM which should be covered by a surface tissue layer and sealing coat.

Table 10.3 — Minimum socket depths

Nominal pipe size	Minimum socket depth (L_2)			
	Pressure (bar)			
	⩽ 2.5	⩽ 4	⩽ 6	⩽ 10
	mm	mm	mm	mm
⩽ 40	25	25	25	25
50	36	36	36	36
65	40	40	40	40
80	40	40	40	40
100	50	50	50	50
125	60	65	65	65
150	65	65	70	75
200	75	75	75	80
250	100	100	100	100
300	100	100	100	100
350	100	100	110	120
400	100	100	120	135
450	105	105	120	145
500	105	110	125	165
550	110	110	140	180
600	110	115	150	200
650	115	115	160	220
700	115	120	175	235
750	120	120	190	250
800	120	120	200	265
850	125	130	215	285
900	135	135	225	300
950	145	145	240	325
1 000	150	150	250	—
1 050	150	150	250	—
1 100	150	180	280	—
1 150	150	200	320	—
1 200	190	200	320	—

NOTE The values given are applicable to pipes based on polyester or epoxide resins. For pipes based on furane resins, the values should be increased by a factor of 1.4.

10.5 Spigot and socket joints in lined pipes

When PVC-U is the lining material injection moulded fittings with sockets suitable for solvent cementing may be used. In such cases the following requirements should apply.

a) PVC-U pipe should conform to the requirements of either BS 3505 or BS 3506 and should not exceed 150 mm nominal size.

b) Fittings should conform to the requirements of BS 4346-1. The use of moulded stub or full face flange fittings with sockets should not be considered permissible.

c) Solvent cement for joints in PVC-U linings should comply with the requirements of BS 4346-3 and should be chosen such that the chemical resistance of the joint is applicable for the chemical conditions of the pipe.

d) Jointing procedures should follow the recommendations of CP 312-2.

e) Before application of the glass reinforcement all external steps at the joints should be blended into the pipe surface with a minimum taper of 1 in 6 using a filled resin paste.

f) The design temperature of systems incorporating injection moulded fittings should not exceed 40 °C and the design pressure should not exceed 6 bar.

10.6 Flanged joints

Flanged joints are classified according to type as follows.

a) Type A: stub flange with backing flange.

b) Type B: full faced flange without backing ring.

c) Type C: full faced flange with backing ring.

Full faced flanges may be used with full faced gaskets but should not be used for mating to raised face flanges.

Prototype testing should be carried out on all flange designs to show that the flanged joint will seal under the combined force of maximum design pressure and applied bending moment when calculated from the following equation:

$$M = 2I\,\{E\epsilon_d - (pD_i/4t)\}/(D_i + 2t_d) \qquad (10.1)$$

where

M is the applied moment (in N·mm);

I is the second moment of area (in mm⁴);

E is the modulus of elasticity (in MPa);

ϵ_d is the design strain;

D_i is the internal diameter (in mm);

t_d is the design thickness of the reference laminate (in mm).

Unless there are records of satisfactory operating performance each flange design should be proved by test. The test pressure on flange joints up to 600 mm should be six times the rated pressure for the pipes with a pressure rating up to 10 bar. In the case of gasket leakage a lower pressure may be agreed. Figure 10.2 and Table 10.4 to Table 10.7 give guidance on flange construction and dimensions.

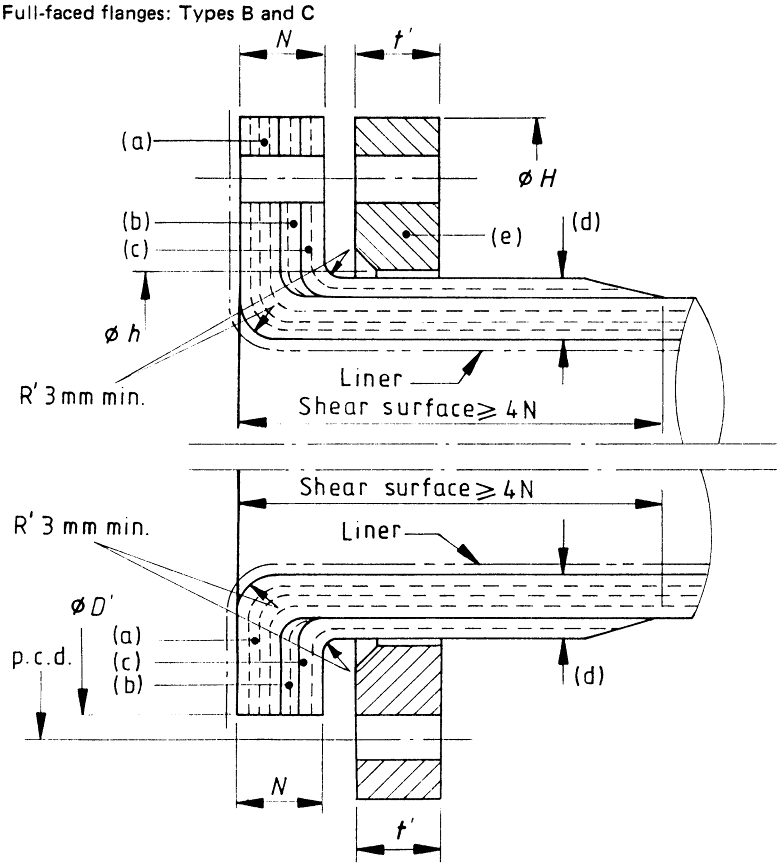
10.7 Environmental conditions

Jointing should only be carried out under environmental conditions compatible with producing satisfactory joints.

The air temperature during jointing should be at least 5 °C unless special arrangements are agreed to ensure that the resin system will gel and cure satisfactorily. These special arrangements may take the form of local space heating or application of a heating blanket. Under all temperature conditions the resin system should be formulated such that the resin in the joint gels within 1 h after the application of the reinforcement layers has been completed.

Jointing should not be permitted under dew point (condensation) conditions. When necessary, the joint area should be protected from inclement weather conditions.

Full-faced flanges: Types B and C



Stub flanges: **Type A**

NOTE 1 Above 40 mm nominal bore types B and C to be used only by agreement between the purchaser and the manufacturer.

a) Pipe wall CSM and WR continuing into flange face.

b) Additional glass reinforcement as required to give flange thickness.

To be tapered on to the hub.

NOTE 2 The additional glass reinforcement may be included in either a) or c).

c) Final overlay of 1.2 kg/m² CSM across flange into hub.

d) Hub thickness ⩾ *N*/2.

NOTE 3 This requirement may be satisfied by pipe wall reinforcement alone.

e) Steel backing flange not less than 6 mm thick and flat over the full bearing area to be used for pressure duties.

NOTE 4 The clearance between the bore of the backing flange and the outside diameter of the hub should be as small as practicable.

NOTE 5 For flange dimensions see Table 10.4 to Table 10.7 as applicable.

Figure 10.2 — Flange construction

Table 10.4 — Flange and bolt details for flanges to BS 1560 Class 150 dimensions $1^1/_2''$ to 24″

Stub flange						Backing flange							Bolt torque	
Root radii $R' \geqslant 3$ mm			Thickness (N)					Thickness (t')	Drilling					
			Strain class[a]	Pressure bar										
			1 and 2	6	10			Pressure					Pressure	
Nominal size	Inside diameter (D_i)	Stub OD (D')	3	3	8	ID[b] (h)	OD (H)	bar	Bolt size (inch)	No. of bolts	Hole size	p.c.d.	bar	
			4	2	6			10					6	10
	mm	mm		mm	mm	mm	mm	mm			mm	mm	N·m	N·m
40	40	135[c]			10	67	135	10	0.5	4	15.9	98		25
50	50	102			10	78	152	10	0.625	4	19.0	121		20
80	80	133			11	112	190	10	0.625	4	19.0	152		25
100	100	172			15	142	229	12	0.625	8	19.0	191		20
150	150	219			17	186	279	13	0.75	8	22.2	241		35
200	200	276			20	237	343	15	0.75	8	22.2	298		45
250	250	337			24	298	406	18	0.875	12	25.4	362		55
300	300	406			29	365	483	21	0.875	12	25.4	432		75
350	350	448		25	29	423	533	22	1.00	12	28.6	476	70	95
400	400	511		29	32	467	597	24	1.00	16	28.6	540	70	95
450	450	546		27	30	508	635	25	1.125	16	31.8	578	75	115
500	500	603		30	34	564	698	27	1.125	20	31.8	635	70	115
550[c]	550	648		32	36	614	756	30	1.125	20	31.8	692	80	120
600	600	714		34	38	669	813	32	1.25	20	34.9	749	100	170

NOTE See Figure 10.2 for definitions of reference letters.

[a] See Table 4.3.

[b] ID of outer edge of chamfer is 6 mm greater.

[c] Non-standard.

Table 10.5 — Flange and bolt details for flanges to BS 3293 Class 150 dimensions 26″ to 48″

Stub flange						Backing flange								Bolt torque	
Root radii $R' \geqslant 3$ mm			Thickness (N)					Thickness (t')		Drilling					
			Strain class[a]	Pressure bar				Pressure bar						Pressure bar	
			1 and 2	4	6										
Nominal size	Inside diameter (D_i)	Stub OD (D')	3	3	4	ID[b] (h)	OD (H)	4	6	Bolt size (inch)	No. of bolts	Hole size	p.c.d.	4	6
			4	2	3										
	mm	mm		mm	mm	mm	mm	mm	mm			mm	mm	N·m	N·m
650	650	772		32	38	705	870	25	27	1.25	24	34.9	807	90	100
700	700	829		34	39	755	927	27	29	1.25	28	34.9	864	90	100
750	750	880		35	41	805	984	27	30	1.25	28	34.9	914	95	115
800	800	937		36	42	855	1 060	29	32	1.5	28	41.3	978	130	155
850	850	988		38	45	914	1 111	29	33	1.5	32	41.3	1 029	130	165
900	900	1 045		40	47	964	1 168	31	35	1.5	32	41.3	1 086	130	165
950	950	1 108		42	49	1 014	1 348	33	37	1.5	32	41.3	1 148	150	185
1 000	1 000	1 159		43	50	1 064	1 289	34	39	1.5	36	41.3	1 200	135	170
1 050	1 050	1 216		45	52	1 114	1 346	36	41	1.5	36	41.3	1 257	155	190
1 100	1 100	1 273		46	54	1 164	1 403	38	43	1.5	40	41.3	1 315	150	190
1 150	1 150	1 324		48	55	1 216	1 454	38	44	1.5	40	41.3	1 365	155	205
1 200	1 200	1 381		50	58	1 269	1 511	40	46	1.5	44	41.3	1 422	155	205

NOTE See Figure 10.2 for definition of reference letters.

[a] See Table 4.3.

[b] ID of outer edge of chamfer is 6 mm greater.

Table 10.6 — Flange and bolt details for flanges to BS 4504 Table 10 (PN 10) dimensions 1″ to 24″

Stub flange						Backing flange							Bolt torque	
Root radii $R' \geq 3$ mm			Thickness (N)					Thickness (t')	Drilling					
			Strain class[a]	Pressure bar				Pressure					Pressure	
			1 and 2	6	10			bar					bar	
Nominal size	Inside diameter (D_i)	Stub OD (D')	3	4	8	ID[b] (h)	OD (H)	10	Bolt size (metric)	No. of bolts	Hole size	p.c.d.	6	10
			4	3	6									
	mm	mm		mm	mm	mm	mm	mm			mm	mm	N·m	N·m
40	40	158[c]			10	67	158	10	M16	4	18	110		25
50	50	106			10	71	165	10	M16	4	18	125		20
80	80	141			11	103	200	10	M16	8	18	160		25
100	100	161			15	133	220	12	M16	8	18	180		20
150	150	217			17	179	285	13	M20	8	22	240		35
200	200	272			20	237	340	15	M20	8	22	295		45
250	250	327			24	298	395	18	M20	12	22	350		55
300	300	377			29	365	445	21	M20	12	22	400		75
350	350	437		25	29	405	505	22	M20	16	22	460	70	95
400	400	488		29	32	467	565	24	M24	16	26	515	70	95
450	450	538		27	30	508	615	25	M24	20	26	565	75	115
500	500	593		30	34	564	670	27	M24	20	26	620	70	115
550	550	645		32	36	614	730	30	M27	20	30	675	80	120
600	600	695		34	38	669	780	32	M27	20	30	725	100	170

NOTE See Figure 10.2 for definition of reference letters.

[a] See Table 4.3.

[b] ID of outer edge of chamfer is 6 mm greater.

[c] Non-standard.

Table 10.7 — Flange and bolt details for flanges to BS 4504 Table 10 (PN 10) dimensions 26″ to 48″

Stub flange						Backing flange								Bolt torque	
Root radii $R' \geqslant 3$ mm			Thickness (N)					Thickness (t')		Drilling				Pressure	
			Strain class[a]	Pressure bar				Pressure							
			1 and 2	4	6			bar						bar	
			3	3	4										
Nominal size	Inside diameter (D_i)	Stub OD (D')	4	2	3	ID[b] (h)	OD (H)	4	6	Bolt size (metric)	No. of bolts	Hole size	p.c.d.	4	8
	mm	mm		mm	mm	mm	mm	mm	mm			mm	mm	N·m	N·m
650[c]	650	755		22	25	705	845	22	25	M27	24	30	785	70	80
700	700	810		32	37	755	895	24	27	M27	24	30	840	75	95
750[c]	750	860		32	38	805	950	24	28	M27	28	30	890	70	90
800	800	917		34	40	855	1 015	26	30	M30	24	33	950	95	130
850[c]	850	967		36	42	914	1 065	26	31	M30	28	33	1 000	90	120
900	900	1 017		37	43	964	1 115	27	33	M30	28	33	1 050	95	135
950[c]	950	1 074		38	44	1 014	1 185	28	34	M33	28	36	1 110	110	165
1 000	1 000	1 124		39	45	1 064	1 230	30	36	M33	28	36	1 160	120	175
1 050[c]	1 050	1 174		40	46	1 114	1 285	30	37	M33	32	36	1 210	110	170
1 100	1 100	1 231		41	48	1 164	1 350	32	39	M36	28	39	1 270	150	230
1 150[c]	1 150	1 291		44	50	1 216	1 410	34	41	M36	32	39	1 330	140	220
1 200	1 200	1 341		45	52	1 269	1 455	35	43	M36	32	39	1 380	150	230

NOTE See Figure 10.2 for definition of reference letters.
[a] See Table 4.3.
[b] ID of outer edge of chamfer is 6 mm greater.
[c] Non-standard.

Section 11. Quality assurance

11.1 General

Pipework and fittings produced to this code of practice should only be made by those manufacturers who are competent and suitably equipped to fulfil all the requirements of quality assurance.

Compliance with these recommendations should be demonstrated by documentation, systems and records as required by the relevant Parts of BS 5750 or another quality system equivalent to EN 29000, EN 29001, EN 29002 or EN 29003 as applicable.

For inspection purposes, especially for the assessment of thickness, structure or physical irregularities such as delamination, some guidance on non-destructive testing (NDT) is given in Appendix E.

11.2 Materials

All materials should be certified or otherwise be shown to conform to the relevant British Standards or equivalent.

All materials should be stored in accordance with the material supplier's recommendations. Documentation of these requirements should be maintained for record purposes.

11.3 Conditions in works

Manufacture of pipework and fittings should be under controlled environmental conditions of temperature, humidity and cleanliness consistent with good engineering practices. Adequate air movement and light should be maintained at all times consistent with factory procedures.

The temperatures of the working area should be maintained above 15 °C for any laminating process.

Should laminating have to be carried out at a lower temperature than 15 °C then special procedures may be adopted to ensure that the resin will cure satisfactorily. However, in no case should the maximum proportion of curing agent exceed the recommendations of the resin supplier.

11.4 Conditions on site

Periodic inspections should be organised to check compliance with the recommendations of **10.7**.

11.5 Workmanship

The manufacturer should show that the fabricators and laminators have been instructed in the techniques and skills required to produce the pipework and fittings in accordance with this code.

Compliance with this recommendation should be demonstrated either by documented evidence of training or, where this is not available, by the manufacture of test samples in accordance with Appendix F.

11.6 Thermoplastics linings

11.6.1 General

The thickness of the lining should not exceed 10 mm for the internal surface of the pipe or 6 mm for a flange face unless the lining is based on PVC and intended for use when the operating temperature is above 40 °C, in which case experience has shown that the use of thicknesses in excess of 4.5 mm can lead to problems in service.

Except for linings made of PP, the minimum thickness of the lining should be 3 mm unless otherwise agreed, in which case for linings based on PVC the minimum thickness should not be less than 2.5 mm. In the case of PP linings, the minimum thickness should be 1.5 mm for lining pipes having a nominal internal diameter of up to 80 mm or 2.0 mm for lining larger pipes.

NOTE To enable compliance with the foregoing limits given for thickness, attention is drawn to the fact that the recommendations given in **3.5** do not imply that extruded PVC profiles for use as linings are necessarily to be made in accordance with the dimensional or related performance requirements of BS 3505 or BS 3506, particularly for linings for pipes having a nominal internal diameter in excess of 100 mm.

Linings of PP, PVDF, FEP, ECTFE and PCTFE should have bonded fabric backings or an etched surface to provide the correct bond.

PVC surfaces should either:

a) be primed using a solvent based primer; or

b) be reinforced initially with a bonding resin and CSM reinforcement.

All welders engaged on fabrication should be approved before fabrication commences. All PVC sheet should be stress relieved in an oven at 120 ± 5 °C for a minimum of 20 minutes.

All sheet forming operations requiring high deformation, such as right angled folds or small radius bends, should be performed with assistance of heat.

All welds should be fully penetrating and free from notches and pinholes.

All welds should be ground flat within 1 mm of the surface. The weld area should be feathered by application of a thixotropic resin paste of the bonding resin.

The thixotropic paste should contain 30 % carbon or graphite to facilitate spark testing after manufacture.

The strength of all welds should be at least 70 % of the strength of the parent material if tested in accordance with Appendix C of BS 4994:1987. The strength of all welds with an internal sealing run and all machine welds should be at least 85 % of the strength of the parent material when similarly tested.

The method of repairing any weld irregularities should be by agreement and should depend on the number, size, type and distribution of any such irregularities.

11.6.2 Hot gas welding

All welds should consist of a minimum of three runs of 3 mm diameter welding rod. All flanges and all pipework above 24 inches NB (nominal bore) should have an additional sealing run applied to the inner surface of the pipe where accessible.

Compressed air or nitrogen should be free from moisture, dirt and oil.

In all cases the grade of the filler rod should be compatible with the material being welded.

All edges to be welded should be chamfered at an angle of 60° to the surface. Before welding commences the edges to be welded, together with the filler rod, should be cleaned and degreased and any fabric backing stripped for a distance of 3 mm to 6 mm to ensure that no filaments are included in the weld.

11.6.3 Other welding methods

Use of welding methods other than those described in **11.6.1** or **11.6.2**, such as machine butt fusion, should be agreed.

11.7 Spark testing of welds

All welds should be spark tested.

Either a.c. or d.c. spark generators may be used. The out-put voltage of the generator should be 20 kV minimum with a spark length of about 20 mm except for testing linings $\leqslant$ 4 mm thick, in which case the output voltage may be reduced to not less than 5 kV/mm thickness of the lining if the lining would otherwise be damaged by test conditions using 20 kV.

Care should be taken not to let the spark play on one place as this may cause degradation.

Metallized tape, wire or other conducting material should be used as a temporary earthing medium.

The probe should be moved over the weld so that the distance between the probe and earthing medium is always less than the spark length.

Sufficient time should elapse between welding and spark testing to ensure that the welded area has cooled and contracted to its final shape.

Initial spark testing should be carried out after the first run of filler rod has been deposited.

Final spark testing should be carried out on completion of the last welding run or, in the case of pipe systems having a permanent earthing medium, after completion of the cure of the reinforcing laminate.

11.8 Lay-up

Proper lay-up should ensure that the pipe construction consists of the inner liner backed by 1.2 kg/m^2 chopped strand mat (CSM) glass fibre impregnated with the resin followed by the required layers of resin impregnated CSM or other reinforcement and finished with a resin-rich tissue reinforced outer surface layer.

Thermoplastics surfaces should be cleaned and degreased prior to application of the bonding layer.

The primer or bonding resin should be designated specifically to promote adhesion between the PVC liner and the laminate resin and should not limit the performance of the pipe.

For GRP pipe the inner surface (sometimes referred to as the "gel coat") and outer surface should be resin rich and reinforced with one or two layers of C-glass or synthetic fibre tissue. The thicknesses of these surfaces should be 0.25 mm to 0.5 mm for surfaces reinforced with one layer or 0.5 mm to 0.8 mm for surfaces reinforced with two layers of tissue.

The glass content by mass of laminate layers reinforced by chopped strand mat should be 25 % to 40 %, for woven roving cloth 45 % to 60 %, and for continuous rovings 50 % to 75 %.

The thickness of the resulting reference laminates for straight pipes should comply with the applicable tolerance given in Table 5.6.

The requisite amounts of resin, catalyst and accelerator, and permitted additives should be accurately measured and thoroughly mixed. The amounts of mixed resin and reinforcement used in the laminate and the number and type of layers supplied should be recorded. The records should be made available if required.

Complete wetting out of each layer of reinforcement is essential and should be achieved by rolling or other means. Excessive rolling pressure should be avoided so as not to disturb the distribution of the reinforcement or break the fibre strands.

The minimum bond strength of the reinforcement of the lining should be 5 MPa in direct shear when tested in accordance with Appendix C of BS 4994:1987.

The manufacturer should ensure that good adhesion is obtained between successive layers of the laminate and between pipe lengths and added fittings either by appropriate scheduling of the manufacturing operation or by removing the surface of the cured resin to expose the fibres.

Adjacent pieces of CSM or woven roving reinforcement should be overlapped by not less than 25 mm. The edges should be worked out by brushing with a stippling action and all joints should be staggered through the thickness of the laminate.

Care should be taken in applying the applicable tension to the glass reinforcement during application so that the reinforcement does not sag away from the mould or mandrel. This may be assisted by the use of a light scrim netting. In order to prevent resin drainage pipes should be continuously rotated prior to gelation.

Any spillage, drips or runs which may flake loose after curing should be removed.

All cut edges should at the appropriate stage be coated with resin so that no glass fibres are exposed. All crevices between jointed sections should be filled where accessible with resin paste.

In the case of polyester resin based laminates, after application of the final outer surface tissue layer on pipes, fittings and joints, a flow coat containing 0.4 % to 0.6 % by mass of paraffin wax in the resin should be applied to minimize the effects of air inhibition. This flow coat should not be applied in areas which subsequently form part of a joint preparation (see **10.1.2**).

Recommended limits for laminate irregularities are given in Table 11.1. Laminates containing irregularities on the process surface which infringe these limits should be rejected.

Laminates containing on the non-process surface irregularities which infringe these limits should be either replaced or repaired by grinding out the affected area and relaminating except for those containing cracks, which should be rejected. For guidance on repair procedures see Appendix G.

11.9 Cure

The manufacturer should cure all items in accordance with the resin manufacturer's recommendations. Whenever possible this should be done at the manufacturer's works and should include an elevated temperature post cure for three hours at 80 °C.

For aggressive solvent duties the minimum final post cure temperature should be 105 °C. Note that in all cases an initial post cure at a reduced temperature is also essential.

In all cases the curing procedure should be such as to produce laminates which satisfy the applicable surface hardness requirements, the solvent test and the residual styrene content.

Special consideration should be given to resins containing fillers, particularly carbon or graphite, to ensure that the presence of the filler does not inhibit the resin cure.

Appropriate precautions should be taken to minimize styrene loss, drainage and low exotherm, especially in laminates less than 6 mm thick.

11.10 Marking

Each pipe and fitting should be permanently marked to include the following information:

a) manufacturer's name or identification mark;

b) nominal size (see **2.2.1**);

c) pressure rating (see **5.2**);

d) resin type (see **3.1**);

and as applicable

e) thermoplastics liner material (see **3.5**);

f) suitability for use with potable water (see **3.7**);

g) vacuum rating (see section 6);

h) reference details of product specification for the pipe or fitting, e.g. the number and date of publication of an applicable British Standard.

11.11 Inspection

The manufacturer should have a separate inspection department not responsible to the production department.

The purchaser's inspector should have free access to the works of the manufacturer and his agreed sub-contractor at all reasonable times. He should be at liberty to inspect the work at any stage, either at the manufacturer's works or on site, and to reject any materials or workmanship that does not conform to the recommendations of this code. He should inspect all test pieces used for assessing the competence of jointers and laminators, witness some of the manufacture and carry out an assessment of all tests.

Table 11.1 — Irregularities and limits thereon

Irregularity	Inner (process) surface (GRP pipework)	Outer (non-process) surface and pipe wall
Blisters	None	Max. 6 mm diameter, 1.5 mm high
Chips	None	Max. 6 mm provided it does not penetrate the reinforcing laminate
Cracks	None	None
Crazing	None	Slight
Dry spots	None	Max. 10/m^2 with none greater than 100 mm^2 in area
Entrapped air	None at surface. If in laminate 1.5 mm diameter max. and 2/cm^2 max.	3 mm diameter max.; no more than 3 % of the area
Exposed glass	None	None
Exposed cut edges	None	None
Foreign matter	None	None if it affects the properties of the laminate
Pits	Max. 3 mm diameter × 0.5 mm deep, number not exceeding 1 per 10^4 mm^2 area	Max. 3 mm diameter × 1.5 mm deep, number not exceeding 1 per 10^4 mm^2 area
Scores	Max. 0.2 mm deep	Max. 0.5 mm deep
Surface porosity	None	None
Wrinkles	Max. deviation 20 % of wall thickness but not exceeding 3 mm	Max. deviation 20 % of wall thickness but not exceeding 4.5 mm
Sharp discontinuity	Max. 0.5 mm (see also **10.1.4**)	Max. 1 mm

All pipework and fittings should be inspected by the manufacturer in accordance with Appendix H.

All items of pipework and fittings should contain an identification reference permanently attached.

11.12 Testing

All pressure and vacuum tests should be carried out in the presence of the inspecting engineer.

Where pipework is required to be hydraulically tested the test pressure should be 1.3 times the design pressure. The pressure should be maintained for a minimum of 30 min, during which period no loss of pressure by leakage should be allowed.

All tests should be carried out with water at ambient temperature. Safety precautions should be taken to ensure that the system is not over-pressurized.

Where pipework is required to be vacuum tested the test pressure should be 1.3 times the design pressure (negative value) or full vacuum, whichever gives the lesser equivalent external pressure. The test pressure should be held for a minimum of 30 min.

On completion of the test pipework fittings should be examined externally and, where practicable, internally. Any evidence of damage, cracking or crazing of the inner resin surface should be cause for rejection.

The gaskets used in the pressure testing should be those specified for the piping system when installed.

Test certificates in duplicate should be supplied to the purchaser.

Appendix A Requirements for non-metallic materials for use in contact with potable water

When used under the conditions for which they are designed, non-metallic materials in contact with or likely to come into contact with potable water shall comply with BS 6920-1.

NOTE 1 Products for installation and use in the United Kingdom which are verified and listed under the UK Water Fittings Byelaws Scheme[6] are deemed to satisfy the requirements of this clause.

NOTE 2 Pending the determination of suitable means of characterizing the toxicity of leachates from materials in contact with potable water, materials approved by the Department of the Environment Committee on Chemicals and Materials of Construction for use in Public Water Supply and Swimming Pools are considered free from toxic hazard for the purposes of compliance with this clause. A list of approved chemicals and materials is available from the Technical Secretary of that Committee at the Department of the Environment, Water Division, Romney House, 43 Marsham Street, London SW1P 3PY.

Appendix B Determination of design strain from mechanical test data

B.1 Determination of design strain of GRP pipe by creep rupture

B.1.1 ***Principle***

Measurements of failure periods for test pieces of pipe when subjected to various internal pressures by a selected liquid environment are used to estimate the 95 % lower confidence limit for the pressure that would produce failure of the pipe in the design service life. This limit is used in conjunction with a known or measured value for the applicable laminate unit modulus to calculate the predicted 95 % lower confidence limit of strain to produce pipe failure at the design service life.

B.1.2 ***Apparatus***

The apparatus shall incorporate the following items:

a) one or more tanks containing water to submerge the test pieces (see **B.1.3**);

b) devices to seal the ends of each test piece and which transmit the entire end load to the ends of the test piece;

c) a means of hydrostatically pressurizing each test piece independently.

B.1.3 ***Test pieces***

Test pieces shall be cut from pipe(s) of the same classification to a length which shall not be less than that necessary to provide a clear length between the end seals of 1.5 times their normal nominal diameter. A minimum of 25 test pieces of equal length is required.

B.1.4 ***Test conditions***

The tests shall be conducted at 18 °C unless the pipes are required for an application involving temperatures higher than 30 °C, in which case the tests shall be conducted at the maximum service temperature.

B.1.5 ***Procedure***

Measure and record the mean internal diameter of each test piece to an accuracy of 1 mm and the mean wall thickness to an accuracy of 0.5 mm. Fill the test pieces with the selected liquid environment pressurized to the selected pressure (see **B.1.6**) and adjusted periodically to keep it within ± 6 % of the selected test pressure until failure occurs, where failure is indicated by the transmission of the test fluid through the test piece wall in any manner, whether it be wall fracture, localized leaking or weeping as evidenced by a continuous loss of pressure in excess of 0.2 % per hour of the test pressure. Note the time between pressurization and failure for each test piece.

B.1.6 ***Test schedule***

Choose for use at least five pressure levels so as to obtain at least five failures in each of the following time bands:

Band 1	10 h to 50 h
Band 2	> 50 h to 250 h
Band 3	> 250 h to 1 250 h
Band 4	> 1 250 h to 6 250 h
Band 5	> 6 250 h

B.1.7 ***Calculation***

Use the least squares method to determine the constants b and c for the regression line:

$$\log(\text{time}) = b \log(\text{pressure}) + c \qquad \text{(B.1)}$$

where

log (pressure) is the independent variable to be obtained (see note 1).

Calculate the 95 % lower confidence level of pressure predicted to produce failure at the design service life (see note 1).

[6] Information is available from WRc Water Byelaws Advisory Service, 660 Ajax Avenue, Slough, Berkshire, SL1 4BG.

Obtain the design strain for failure at the design service life from the equation:

$$\epsilon_d = p_{95} D_i / 26 X_{LAM} \quad \text{(B.2)}$$

where

- p_{95} is the 95 % lower confidence limit of the internal pressure (gauge) (in bar) to produce failure at the design life;
- D_i is the internal diameter of pipe (in mm);
- X_{LAM} is the laminate unit modulus (in N/mm) (see notes 2 and 3).

NOTE 1 The method of obtaining the regression line by least squares and the 95 % lower confidence level of pressure can be found in ASTM D 2992-71.

NOTE 2 If the value of X_{LAM} is not known, it may be obtained by performing burn-off tests in accordance with BS 2782:Method 1002 to determine the mass of glass in a test piece for each pipe tested and using the lay-up pattern for the pipe and mean values for the required mass of glass to calculate the unit moduli and laminate unit modulus in accordance with **4.2.2.6**.

NOTE 3 The preceding value of 26 incorporates a safety factor of 1.3.

B.1.8 ***Test report***

The test report shall include the following:

a) the size and classification of the pipe;

b) graphs of log pressure and log time to failure, together with a plot of the straight line obtained by least squares and the values of *b* and *c* [see equation (B.1)] with their correlation coefficient;

c) the predicted 95 % lower confidence value of strain producing failure at the design life (i.e. ϵ_d);

d) the description of the liquid used to pressurize the test pieces;

e) a reference to this method of test, e.g. clause **B.1** of BS 7159:1989;

f) the dates between which the pressure tests were conducted.

B.2 Determination of environmental effects by fatigue tests on GRP pipe material

B.2.1 ***Principle***

This method describes the test procedure to compare the effects of a fluid environment on GRP pipe material with that of a reference fluid environment by fatigue tests.

B.2.2 ***Apparatus***

B.2.2.1 *Fatigue machine*, capable of holding a strip of GRP material and applying an alternating tensile force at a frequency of 10 Hz to 15 Hz and recording the endurance to failure.

B.2.2.2 *An environmental chamber*, capable of enclosing the test piece and containing the fluid environment required to be in contact with the test piece (see **4.3.3**).

B.2.3 ***Test pieces***

Strips of material having dimensions in accordance with ASTM D 3093-76 as applicable shall be cut from the pipe wall, if the pipe diameter is large enough, otherwise from boards fabricated in the same lay-up as the pipe material. All cut edges should be sealed using the matrix resin.

B.2.4 ***Test conditions***

The tests shall be conducted at 18 °C unless the pipes are required for an application involving temperatures higher than 30 °C, in which case the tests should be conducted at the maximum service temperature.

B.2.5 ***Procedure***

Mount a test piece in the fatigue machine with part or all of the test piece surrounded by an environmental chamber containing a specified liquid environment in contact with the test piece. Select and apply a tensile fatigue test at 10 Hz to 15 Hz using a peak force that will produce failure of the test piece, by fracture, in the range 10^3 to 3×10^6 cycles. Record the peak force applied and the number of cycles to failure.

B.2.6 ***Test schedule***

For each liquid environment, repeat the procedure given in **B.2.5** until a minimum of 12 test pieces have been tested in all using at least four peak stress levels chosen to cause the results from the failures of the test pieces to be spread over all the following endurance bands:

Band 1	10^3 to 10^4 cycles
Band 2	10^4 to 10^5 cycles
Band 3	10^5 to 10^6 cycles
Band 4	10^6 to 3×10^6 cycles

B.2.7 ***Calculation***

Use the least squares method (see note 1) to determine the constants *b* and *c* for the regression line for:

$$\text{Log } n_f = b \text{ Log } \sigma_{max\,f} + c \quad \text{(B.3)}$$

where

- n_f is the number of cycles to failure;
- $\sigma_{max\,f}$ is the Peak stress (in MPa) of the cycle.

Determine by extrapolation the stress $\sigma_{(10E7)}$ that would cause failure in 10^7 cycles. Calculate the strain at 10^7 cycles, $\epsilon_{(10E7)}$ by using the equation:

$$\epsilon_{(10E7)} = \sigma_{(10E7)}\, t_d / X_{LAM} \qquad \text{(B.4)}$$

where

$\sigma_{(10E7)}$ is the estimated stress (in MPa) that would cause failure in 10^7 cycles;

t_d is the design thickness of the reference laminate (in mm);

X_{LAM} is the laminate unit modulus [in N/mm (per kg/mm² glass)] (see note 2).

NOTE 1 The method of obtaining the regression line by least squares and the 95 % lower confidence level of pressure can be found in ASTM D 2992-71.

NOTE 2 If the value of X_{LAM} is not known, it may be obtained by performing burn-off tests in accordance with BS 2782:Method 1002 to determine the mass of glass in a test piece for each pipe tested and using the lay-up pattern for the pipe and mean values for the required mass of glass to calculate the unit moduli and laminate unit modulus in accordance with **4.2.2.6**.

B.2.8 *Test report*

The report shall include the following:

a) the size and classification of the material;

b) the nature and strength of the environment;

c) graphs of log n_f and log stress for each environment together with a plot of the straight line obtained by least squares and the values of b and c [see equation (B.3)] with their correlation coefficient;

d) the extrapolated value of stress (in MPa) that would cause failure at 10^7 cycles for each environment;

e) the estimated strain at 10^7 cycles;

f) a reference to this method of test, e.g. clause **B.2** of BS 7159:1989;

g) the date of testing.

Appendix C Notes on flexibility and stress analysis

C.1 Expansion coefficients

C.1.1 *GRP (unlined)*

The expansion coefficient varies between 20×10^{-6} and 30×10^{-6} per °C, i.e. between 1.7 and 2.5 times that of carbon steel depending on the type(s) of reinforcement used in the pipe wall. Constructions using only CSM are at the upper end of the range. Incorporation of continuous roving into the construction, whether wound directly on to the pipe or applied as woven roving cloth, reduces the coefficient. The coefficient for a particular construction should be obtained from the fabricator.

C.1.2 *GRP (lined)*

As with GRP, the coefficient varies with the type(s) of reinforcement used but the presence of the lining also affects the coefficient of expansion, e.g. PVC has a coefficient of 80×10^{-6} per °C. At low temperature, i.e. up to about 40 °C, the PVC retains its stiffness and hence increases the coefficient of the composite. At higher temperatures the stiffness of the PVC progressively decreases and the coefficient of the composite correspondingly decreases until at temperatures of 60 °C and above the effect of the PVC can be ignored. The coefficient of expansion of PVC-lined GRP varies from 20×10^{-6} to 45×10^{-6} per °C depending on the operating temperature and the type of reinforcement used in the pipe wall.

C.2 Calculation of temperature changes

Because of the high coefficients of expansion and low allowable stresses the expansion of GRP and lined GRP pipework over small temperature ranges can be significant. This means that the temperature at which the erected length of the pipework is determined is important.

a) For pipework in which all site joints will be of the flanged type the erected length of the pipework is, in theory, established in the fabricator's workshop at the relatively steady temperature therein. In practice, however, pipework may be modified or repaired on site and the erected length will then alter depending on the ambient temperature at the time.

b) For pipework in which the site joints are over-wrapped butt joints it is normal practice to fabricate the pipework to be cut to length on site at joint positions. The erected length will again depend on the ambient temperature at the time of erection.

c) When designing pipework or carrying out flexibility and stress analysis it may be unwise to try to predict the temperature at which the pipework will be erected, modified or repaired. The recommended rules are as follows.

1) *Expansion temperature range.* Calculate this assuming that the erected length will be established at the minimum ambient temperature throughout the year or 0 °C, whichever is the higher. For the British Isles use 0 °C.

2) *Contraction temperature range.* Calculate assuming that the erected length will be established at the maximum ambient temperature throughout the year. For the UK use 30 °C.

C.3 General considerations in accommodating expansion and contraction

C.3.1 With some pipework arrangements (e.g. complex small bore installations with small temperature change) it is possible to decide by inspection that no special attention needs to be given to expansion and contraction. When he takes such a decision the engineer is in effect judging:

a) that the pipework will not impose unacceptable loads on anchor points such as vessel or pump branches i.e. that it is flexible enough;

b) that the bends and tees, which are generally the points of highest stress in pipework, are not over-stressed, bearing in mind that GRP is not capable of deforming plastically like steel.

For larger diameter pipework it is often necessary, even taking into account the high natural flexibility of GRP (about 10 to 35 times that of carbon steel), to take special action to accommodate expansion and contraction, particularly if temperature changes in the pipework are large. Calculations are usually required to make sure that anchor loads and pipework stresses are low enough.

C.3.2 As the pipe diameter increases the pipework becomes less flexible and also the stress intensification factors at bends and tees can increase. It is often necessary, particularly if temperature changes in pipework are large, to make special provision to accommodate expansion and contraction and to make calculations to ensure that anchor loadings are acceptable and stresses are within allowable limits.

The conditions that need to be considered are as follows.

a) Normal operation, which may take several forms particularly with sectionalized systems.

b) Start-up, shutdown and abnormal operations. For a system carrying liquid abnormal operation may include the pipework (or part of it) becoming empty while still hot or becoming cold while still full of liquid.

c) Rapid depressurizing, which may cause significant temperature effects.

d) Steaming or washing out.

e) Testing.

f) Relief or other discharge of pipework contents to atmosphere, other pipes or vessels. This may cause reactions on the pipework.

g) Removal of pipework and/or other equipment for maintenance or other reasons.

C.3.3 Before flexibility and stresses can be analysed the following information has to be obtained:

a) mass per unit length of pipe and contents;

b) expansion coefficient of pipe material;

c) modulus of elasticity of pipe material;

d) pipe wall thickness in all parts of the system;

e) type and amount of reinforcement (additional to the reinforcement of the pipe wall) at all bends and tees;

f) lengths over flanges and masses of all valves and other in-line items;

g) pressure in the pipework;

h) the allowable stress(es) in the material;

j) the operating temperature of the line.

C.3.4 If the pipework configuration is simple, an arrangement drawing or sketch is adequate for purposes of flexibility and stress analysis. If the pipework configuration is complex, an isometric drawing of each complete section of pipework requiring analysis should be prepared. The isometric view should show all features which are significant for the purpose of flexibility and stress analysis, i.e. all the information listed in **C.3.3** together with the following.

a) The positions of proposed anchors. Where movement of the anchor occurs, e.g. at vessel nozzles due to expansion of the vessel, the magnitude and directions of movements should be given.

b) The positions and types of proposed supports and guides. The way(s) in which the pipework is constrained by the supports and guides should be indicated. The characteristics of any spring supports should be given.

c) Any significant changes in the pressure within the system, e.g. to a change in static head at a rise or fall in the pipework.

Some points to note are as follows.

1) If spring supports are used to allow vertical movement of the pipework to take place during service, special consideration should be given to the loads which the springs can exert on the pipework when it is in a cold/empty condition. If the plant operates on a batch basis, the variations in spring load can be a factor in fatigue of the pipework. Undesirable spring loads can often be prevented or controlled by the use of limit stops on the springs.

2) Cold pull (or push) should not be used in the design of GRP or lined GRP pipework because:

i) fabrication and erection of the pipework are not sufficiently exact to be sure that the required cold pull will be achieved;

ii) the amount of cold pull would have to be related to the temperature of the pipework on erection. Ambient temperature changes and/or exposure to sunlight can cause significant dimensional changes in GRP but because of the poor heat conductivity of the material it would not be possible to know the average temperature of the pipe wall and hence not possible to determine the required cold pull.

C.4 Accommodation of expansion using bellows units

C.4.1 As far as possible the use of bellows units should be limited to applications in which the bellows accommodate expansion axially, i.e. they are only compressed/extended. Other methods, e.g. transverse displacement of a single bellows or an articulated bellows system, can be used but they need special consideration and expert advice should be obtained.

C.4.2 Where GRP and lined GRP pipework are used for a corrosion resistant application the bellows units used should also be corrosion resistant. Three main types are used as follows.

a) *PTFE bellows units.* For high pressure applications moulded units are used but these accept relatively small amounts of compression/extension. For low pressure duties machined PTFE units can be used which will accept larger amounts of compression/extension but which are relatively flimsy.

b) *Reinforced rubber bellows units.* These can only be used if a type of rubber exists which is suitable for the duty. The reinforcement should be an appropriate synthetic fibre for corrosion resistance.

c) *GRP bellows units.* Flexibility is achieved by using the thinnest practicable wall construction. So far these units have been developed for size use in pipe-work of nominal size 750 or larger; units of small nominal size would be stiffer but may still be feasible. Applications to date have been on duties with very low pressures or suctions. Any application involving significant pressure would require careful consideration because compression/extension is achieved by deflection of flat plate diaphragms.

C.4.3 Note that the normal rules for the design of carbon steel pipework incorporating bellows units apply also to GRP and lined GRP pipework (see reference [2]). Examples of rules which apply to axial bellows units and which are frequently broken are as follows.

a) Only one bellows unit should be fitted between two adjacent anchors.

b) Anchors should be designed to withstand the worst combination of possible loadings. The effects of pressure thrust, bellows stiffness, friction, and, in the case of vertical lines, dead weight should be taken into account.

c) The pipe run between adjacent anchors should be straight.

d) The pipe should be properly guided.

C.4.4 When considering the range of movement of an axial bellows unit both expansion and contraction should be considered. The bellows unit should be able to accept the whole of the possible expansion movement plus the whole of the possible contraction movement.

Example. A main 100 m long will run in a straight line between plant items which act as anchors. It is to be sited in the British Isles and will operate at 90 °C. The chosen axial bellows unit has a neutral length of 200 mm. The allowable bellows deflections are 25 mm compression and 25 mm extension from the neutral position. If the expansion coefficient of the main is 30×10^{-6} per degree, how many bellows units are needed?

Expansion of the main between 0 °C and 90 °C

$= 100\,000 \times 30 \times 10^{-6} \times 90$
$= 270$ mm.

Contraction of the main between 30 °C and – 10 °C

$= 100\,000 \times 30 \times 10^{-6} \times 40$
$= 120$ mm.

Required total bellows movement = 270 + 120
= 390 mm

Number of bellows units required = 390/(25 + 25)
= 8

Thus each bellows unit should be able to accommodate 270/8 = 34 mm of pipe expansion and 120/8 = 15 mm of pipe contraction.

When the main is installed or modified or repaired each bellows unit should be set to length of 200 – 25 + 34 = 209, say 210 mm (from which point it can accommodate 15 mm pipe contraction (which extends the bellows) and 35 mm pipe expansion (which compresses the bellows)

Seven intermediate anchors are required.

Appendix D Dimensional design details of fittings

Nominal dimensions for the lengths and radii of GRP pipework fittings illustrated in Figure D.1 are given in Table D.1 which comprise preferred values to be assumed or specified for the purpose of preparing an initial pipe-work layout drawing. The system layout with its resulting geometric and environmental conditions can be used together with the process conditions and pipework contents as a basis for checking that the proposed laminate constructions for the component pipes and fittings satisfy the limiting design criteria in accordance with this standard and otherwise for changing the layout and/or component structure as appropriate.

An alternative set of dimensions, for relatively short patterns of flanged fittings as illustrated in Figure D.2, is given in Table D.2. Fittings in accordance with Table D.2 should not be specified unless it is essential to use flanged fittings with shorter leg lengths than those obtained by butt-jointing stub flanges to fittings in accordance with Figure D.1 and complying with Table D.1. In either case, bends and reducers may be flanged on one or both ends: tees may be flanged on one, two or three legs.

For unequal tees in accordance with Table D.2, use E_3 as applicable to the branch nominal size and E_2 as applicable to the main line nominal size.

Table D.1 — Nominal dimensions for GRP pipe fittings

Nominal pipe size	All dimensions in mm (see Figure D.1 for their location)							
	D_{iM}, D_{iB}, D or d	A	R	B	C	S_B or S_M	J_{B1} or J_{B2}[a]	G
40	40	150	115	165	100	75	100	50
50	50	150	150	200	125	75	125	50
80	80	175	225	275	150	75	125	50
100	100	200	300	350	175	100	150	50
150	150	225	225	300	175	150	200	75
200	200	275	300	375	200	200	225	75
250	250	300	250	325	175	225	250	75
300	300	350	300	375	200	275	275	75
350	350	400	350	450	250	325	325	100
400	400	450	400	500	275	325	350	100
450	450	475	450	550	275	425	375	100
500	500	500	500	600	300	425	400	100
550	550	550	550	650	325	525	425	100
600	600	600	600	700	325	525	450	100
650	650	475	650	750	350	500	475	100
700	700	500	700	800	375	525	500	100
750	750	525	750	850	400	575	525	100
800	800	550	800	900	425	600	575	100
850	850	575	850	950	425	650	600	100
900	900	600	900	1 000	450	675	625	100
950	950	625	1 050	1 050	475	725	650	100
1 000	1 000	650	1 100	1 100	500	750	675	100
1 050	1 050	675	1 050	1 150	525	800	700	100
1 100	1 100	700	1 100	1 200	525	825	750	100
1 150	1 150	725	1 150	1 250	550	875	775	100
1 200	1 200	750	1 200	1 300	575	900	800	100

[a] J_{B1} is the value corresponding to D_{iB1} and J_{B2} is the value corresponding to D_{iB2}.

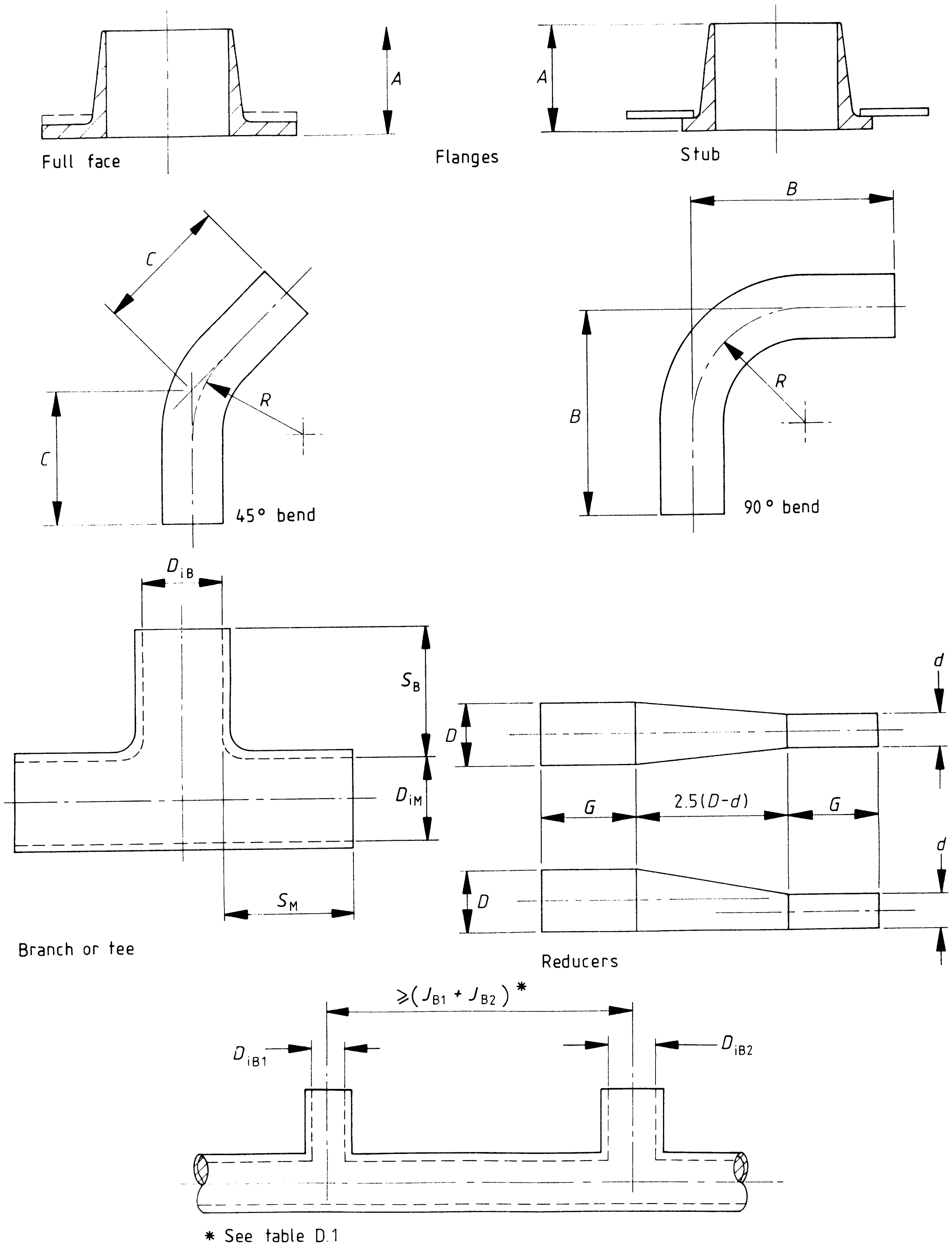


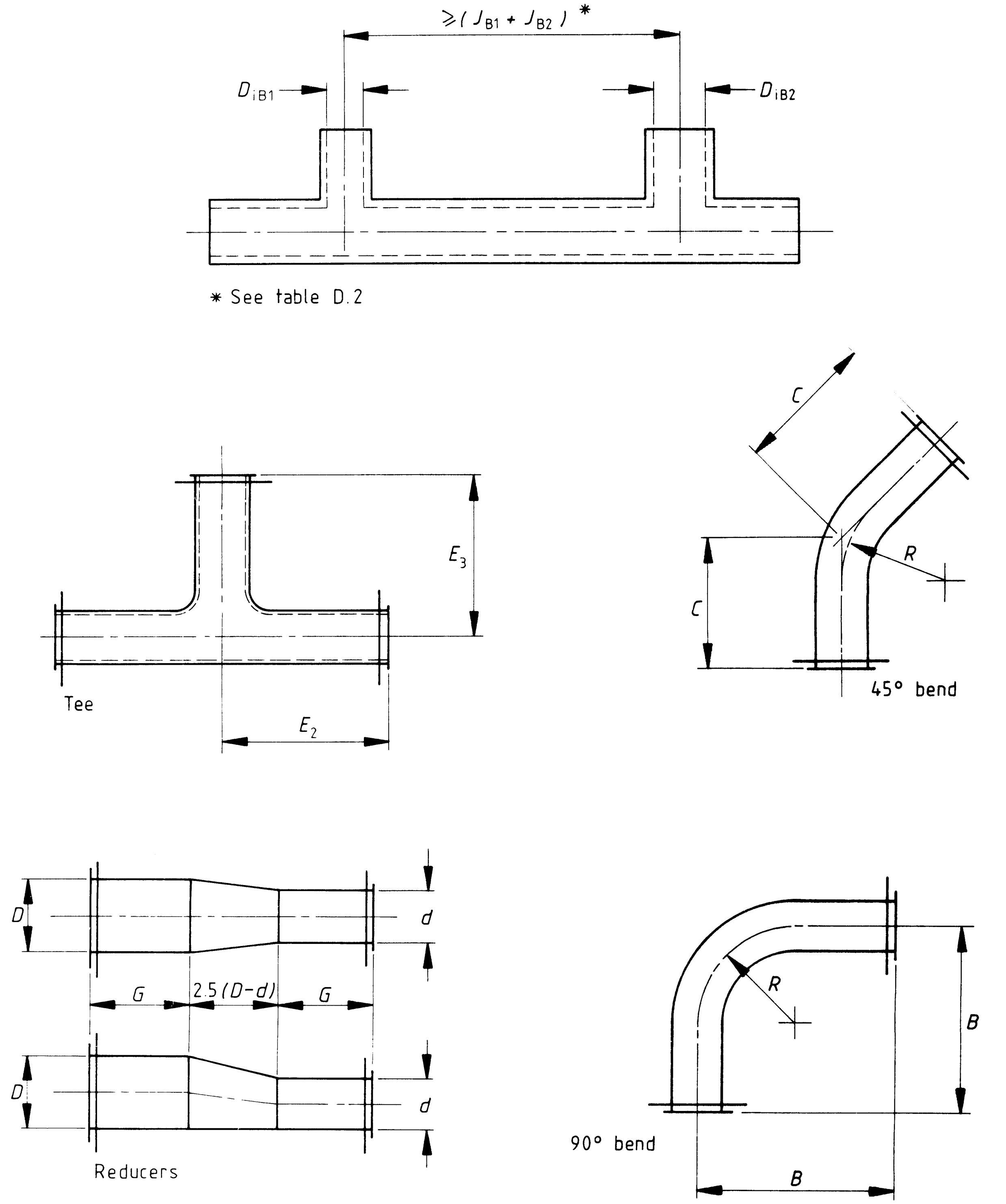
Figure D.1 — Dimensions of GRP pipe fittings

Table D.2 — Nominal dimensions for non-preferred[a] GRP flanged fittings

Nominal pipe size	All dimensions in mm (see Figure D.2 for location)							
	G	E_3	E_2	R	B	C	D_{iB1} or D_{iB2}	J_{B1} or J_{B2}[b]
40	100	150	175	115	225	150	40	100
50	125	175	200	150	275	200	50	125
80	150	200	250	225	375	250	80	125
100	150	200	250	300	450	275	100	150
150	175	225	300	225	400	275	150	200
200	175	250	350	300	475	300	200	225
250	200	275	400	250	450	300	250	250
300	200	275	425	300	500	325	300	275
350	200	275	450	350	550	350	350	325
400	250	325	525	400	650	425	400	350
450	250	325	550	450	700	425	450	375
500	300	400	650	500	800	500	500	400
550	300	400	650	550	850	525	550	425
600	300	400	700	600	900	550	600	450
650	300	400	750	650	950	575	650	475
700	300	400	750	700	1 000	575	700	500
750	300	400	800	750	1 050	600	750	525
800	300	400	800	800	1 100	625	800	575
850	400	500	900	850	1 250	750	850	600
900	400	500	950	900	1 300	750	900	625
950	400	500	950	950	1 350	800	950	650
1 000	400	500	1 000	1 000	1 400	800	1 000	675
1 050	400	500	1 050	1 050	1 450	850	1 050	700
1 100	500	600	1 100	1 100	1 600	950	1 100	750
1 150	500	600	1 100	1 150	1 650	975	1 150	775
1 200	500	600	1 150	1 200	1 700	1 000	1 200	800

[a] The values given in this table for the dimensions shown in Figure D.2 should not be specified unless it is essential to use flanged fittings with shorter leg lengths than those obtained by butt-jointing stub flanges to the fittings shown in Figure D.1 with dimensions in accordance with Table D.1.

[b] J_{B1} is the value corresponding to D_{iB1} and J_{B2} is the value corresponding to D_{iB2}.



NOTE 1 Fittings in accordance with this figure and the dimensions given in Table D.2 should not be specified unless it is essential to use flanged fittings with shorter leg lengths than those obtained by butt-jointing stub flanges to the fittings (see **8.9**).

NOTE 2 For unequal tees, use E_3 applicable to the branch nominal size and E_2 applicable to the main line nominal size.

Figure D.2 — Dimensions of non-preferred GRP flanged fittings

Appendix E Non-destructive testing (NDT)

E.1 Introduction

Of the range of NDT methods commonly used for metals only ultrasonic techniques can be readily and usefully employed for GRP. Moreover the variations of ultrasonic testing which can be applied are very restricted and the information gained may require careful interpretation.

Sophisticated acoustic (AE) techniques have been employed in recent years in the USA for proof-testing of GRP vessels. The method is therefore covered briefly here although its routine use for GRP pipe has yet to become technically established.

The use of the techniques discussed here is not an essential feature of this code but they may be used to assist in quality assurance when agreed between supplier and purchaser.

E.2 Ultrasonic testing

E.2.1 ***General***

This clause provides guidelines for the application of ultrasonic examination to GRP pipe systems. The use of ultrasonic equipment on a routine basis will generally be limited to the monitoring of pipe wall thickness and the detection and sizing of areas of delamination or lack of fibre wet-out.

The ultrasonic properties of GRP severely limit the range of ultrasonic equipment which can be usefully employed, for example, angled shear wave probes of the type widely used in the testing of metallic components are not used for GRP.

The successful application of ultrasonic testing on GRP requires a knowledge of the limitations of the techniques and an understanding of the principles underlying the design and manufacture of GRP equipment. Certain irregularities which may be considered undesirable in metallic components are not significant in GRP laminates.

E.2.2 ***Instrumentation***

The method of most general usefulness is the pulse echo technique employing a single transducer which operates as both a transmitter and receiver of pulsed ultrasound, allowing measurements to be made with access to one side of the component only.

In GRP ultrasonic waves are partially reflected at boundaries between successive glass reinforcement layers. The degree of reflection increases with increasing frequency and is also dependent on the types of reinforcement layer concerned and on the form of the interface (whether resin-rich, for example). The multiple reflections which arise in this manner can render interpretation of ultrasonic signals impracticable in a pulse-echo method. To overcome this problem it is necessary to use a sufficiently low ultrasonic frequency. Too low a frequency, however, can prevent resolution of the reflected signal in the thickness range of interest because of the correspondingly large wavelength concerned. A satisfactory compromise is found within the ultrasonic frequency range of about 0.5 MHz to 1 MHz (compared with the 5 MHz frequency often used with metals).

In practice highly damped compressed-wave transducers are employed for GRP, having a central frequency within the above range and producing short (broad band) ultra-sonic pulses. The ultrasound propagates in a direction normal to the contact surface.

Since the surface of GRP pipe may not be very smooth, the copious use of a suitable couplant grease may be necessary. For the same reason use of an ultrasonic probe with a soft rubber facing on its contact surface may be advantageous.

There are a number of commercially available instruments suitable for use with GRP. Some are primarily designed to provide digital read-out but these should also have a secondary output to allow ultrasonic signals to be displayed on an oscilloscope. Such a facility allows cross-checking of the digital output and increases the operator's confidence in the reliability of the digital information in the presence of the multiple signals arising from partial reflections at reinforcement interfaces. In addition, the facility aids the initial setting up of the equipment if there are frequent changes in the nature of the applications. It also increases the number of quality control applications that may be covered.

E.2.3 ***Equipment calibration***

Calibration of the equipment should be carried out both immediately prior to testing and at regular intervals thereafter.

Calibration blocks should be fabricated to be as close as possible in composition to the pipe wall laminate to be tested. Separate calibration blocks are advisable for CSM, CSM/WR and filament-wound GRP. It is not generally necessary, however, to calibrate for resin type since the variation of the velocity of sound with resin type is relatively insignificant.

The velocity of the sound varies more with temperature than in metals. A change in temperature of 20 °C might result in some circumstances in error as great as 20 % in an ultrasonically measured thickness. Consequently calibration blocks should be the same nominal temperature as the component under examination. Atmospheric humidity changes are not important.

Where irregularities are to be accurately sized, calibration blocks should contain irregularities of the appropriate form. In particular, the position and orientation of irregularities artificially introduced into calibration blocks should be similar to those likely to be found in practice.

Consideration should be given to the retention of "cut-offs" from pipe branches, or cut-outs from mains, since these can provide valuable reference material for subsequent ultrasonic measurements.

E.2.4 ***Thickness measurements***

Metallic pipes are made by semi-automatic machine-based production routes and are supplied at a specified thickness with a small associated tolerance. GRP laminates on the other hand contain unavoidable variations in thickness at, for example, reinforcement overlaps. Reliance on only a small number of thickness measurements may therefore produce misleading conclusions.

The variation in the velocity of ultrasonic waves with glass content in GRP is relatively small up to about 50 % glass (m/m). Assumption of a sound velocity of 2 370 m/s at 0.5 MHz to 1.0 MHz frequency and at ambient temperatures would give thickness errors below + 5 % over a wide range of laminate variations. Whilst this lack of sensitivity to glass content contributes to the accuracy of GRP thickness testing it also means that some care is required in the interpretation of ultrasonic thickness data. Measurement of a particular thickness ultrasonically gives no assurance in respect of glass content, because the laminate parameter is generally of most significance. The ultrasonic thickness test measures the transit time of an ultrasonic pulse which is then translated into a laminate thickness by application of a velocity factor (established by measurement on a calibration block of the desired composition).

The above shortcoming in the usefulness of ultrasonic thickness test results should be clearly recognized by the user.

E.2.5 ***Irregularities or discontinuities***

Ultrasonic waves are readily reflected from air/resin interfaces in the form of delaminations, cracks, dry joints and regions with lack of fibre wet-out. The ultrasonic technique therefore allows ready detection of such discontinuities. Their sizing requires interpretive skills, possibly combined with carefully prepared calibration blocks. It should be noted that crack-like (planar) defects are not readily detected when the plane of the defect lies in the direction of propagation of the ultrasonic waves, i.e. normal to the probe contact face.

Careful consideration must again be given to interpretation of results. In particular, sensible acceptance criteria must be defined for the numbers and sizes of particular types of irregularity. For example, a limited extent of delaminations is probably acceptable in many applications; on the other hand widespread delamination would indicate a very poor quality of lay-up or a fault in the manufacturing process. Voids reflect ultrasonic waves and are therefore possible to detect. Quantification of total void content would, in general, require a series of calibration measurements on laminates with varying degrees of voidage, and also the use of specialized techniques other than the sample pulse echo method. As with other discontinuities soundly based acceptance criteria would be essential.

E.2.6 ***Thermoplastics/lined GRP components***

In components where there is adhesion between GRP and the thermoplastics liner a majority of the ultrasonic wave energy passes through the interface. Hence a pulse echo ultrasonic test will measure a transit time corresponding to the laminate and lining combined. The velocity of sound in the thermoplastics material, which may differ significantly from that in the laminate, can be established by means of a calibration piece. Knowledge of this velocity and of the thickness of the liner will then enable the thickness of the laminate to be derived very simply from ultrasonic results on the liner/laminate combination.

Where there is no bond between GRP and liner then ultrasonic waves will be strongly reflected from the interface. Hence such regions can be readily detected and sized by the pulse echo method and results compared with an acceptance criterion for this type of discontinuity.

E.3 Acoustic emission testing

The examination of GRP equipment using acoustic emission techniques is a complex operation of which there is limited experience within the UK.

The method involves the monitoring of acoustic signals generated within a GRP component by micro-failure mechanisms during pressure testing. Useful interpretation of the signals requires a considerable knowledge of the behaviour of fibre-composite structures under stress, with an understanding of the sources of acoustic signals which such materials generate and of the equipment used to record and analyse these signals.

The major practical work in the field has been that of the Committee on Acoustic Emission from Reinforced Plastics (CARP), a working party of the Corrosion Resistant Committee of the Plastics Industry (SPI) of USA. This work has been concerned with the testing of GRP tanks and vessels and a large number of such components have been analysed using the methods of acceptance criteria defined by CARP. The principles of the CARP approach would represent a sensible starting point for acoustic testing of GRP pipe. However, the acceptance criteria defined in terms of numbers and magnitudes of acoustic signals detected need to be tailored to a particular geometry and size of component, and possibly also to its composition. A prerequisite of routine quality control of GRP pipe components by acoustic emission methods would therefore be the analytical testing of a considerable number of like parts, probably combined with the destructive examination of some of those parts. Only by such testing could realistic and meaningful acceptance criteria be defined.

E.4 Other methods

E.4.1 *Radiographic methods*

Conventional radiographic techniques are likely to offer advantages over ultrasonic methods in rare instances only. For crack-like discontinuities, they offer highest sensitivity for discontinuities oriented normal to the access surface: those irregularities for which ultrasonic methods are very insensitive. Crack-like irregularities of this orientation (i.e. normal to reinforcement layers) are very unlikely to be found in newly fabricated GRP pipe components.

E.4.2 *Eddy current method*

Thickness testing by means of an eddy current method is only feasible if a suitable metallic film or plate is brought into contact with one face of the GRP component, whilst the eddy current probe is applied to the other. This requirement for simultaneous access to both sides of the GRP laminate is likely to limit application of the method.

E.4.3 *Potential methods*

The following are some other NDT methods which might in future provide the basis for routine quality control procedures but which require further development.

a) Ultrasonic spectroscopy, in which the frequency spectrum of reflected ultrasonic pulses are analysed and which could be used, for example, to measure the number of reinforcement layers in a laminate.

b) Radiation back scatter measurements, which might be used to measure glass content of a laminate.

c) Thermal pulse thermography, in which a GRP component is subjected to a burst of heat from an intense source and then examined by an infra-red technique to reveal temperature discontinuities associated with physical discontinuities and delaminations.

Appendix F Procedure approval tests

F.1 General

When specified, the manufacturer should make procedure test pieces simulating pipe, fittings and joint procedure for the work required for the contract.

Procedure test pieces should not be pigmented.

All procedure test fabrications should be made in the presence of the inspecting engineer under conditions simulating those to be used on the whole of the contract, including surface preparation, jigging and positional requirements.

F.2 Procedure test welds

The test plate shall incorporate a 200 mm long butt weld made by jointing two pieces of 3 mm sheet each 200 mm long and 200 mm wide. The weld shall be made in the same manner as the production welds and shall include at least one stop and start in each run.

F.3 Procedure test joints

Test joints shall be made between lengths of pipe not less than 100 mm longer than the joint overlay width.

F.4 Procedure test fittings

When specified, test fittings of types to be used on the contract should be made.

F.5 Assessment of test pieces

All test pieces should be submitted to the inspecting engineer for visual examination and, if acceptable, the manufacturer should send the test piece to the purchaser for destructive testing. This should include, as applicable, pressure testing, tensile testing, sectioning and polishing and determination of glass content; the tests being selected to determine whether the procedure test pieces comply with the applicable parts of the code or specification.

Appendix G Repair procedures

Descriptions of various irregularities which may be observed in GRP pipe or fitting constructions are given in Table G.1 together with a classification of their respective significance and recommended remedial procedures.

Table G.1 — Repair procedures

Irregularities	Definitions	Allowable limits (reproduced from Table 11.1)		Classification of feature	Repair procedure
		Process side	Outside		
Blisters	An air void beneath the laminate surface covered by surface wall.	None	Max. 6 mm dia. 1.5 mm high	Reportable if more than 1 per 2 m^2	Grind out blister to bottom and laminate sufficient glass to bring the area flush. Cover with a surface tissue reinforced layer extending at least 25 mm beyond the underlying repair. Cover with polyester film and smooth out.
Burnt areas	An area of discolouration, delamination and high fibre prominence caused by excessive exotherm.	None	None	Reportable	If translucence is obscured, total area to be ground out and material or 1.2 kg/m^2, whichever is greater, replaced.
Chips	An area of laminate that has been damaged by impact, e.g. during cutting	None	Max. 6 mm with no penetration of reinforcing laminate	If gross, reportable	Cover with a minimum of 1.2 kg/m^2 CSM plus surface covers as for blisters.
Cracks	A split in the laminate.	None	None	Notifiable	To be agreed.
Crazing	An area of damage of cruciform shape caused by impact.	None	Slight	Reportable	Grind out to root. Replace material removed (but not less than 1.2 kg/m^2) plus surface covers as for blisters.
Dry spots	An area of laminate not impregnated with resin.	None	Max. 10/m^2 with none greater than 100 mm^2 in area	Notifiable	To be agreed.
Entrapped air	Bubbles of air in the laminate.	None at surface. If in laminate 1.5 mm max. dia. and 2/cm^2 max.	3 mm max. dia. No more than 3 % of area.	Reportable if within 10 % of limit.	If near surface grind out then cover with 1.2 kg/m^2 CSM plus surface covers as for blisters. Limits then for outside to apply.

Table G.1 — Repair procedures

Irregularities	Definitions	Allowable limits (reproduced from Table 11.1)		Classification of feature	Repair procedure
		Process side	Outside		
Exposed glass	Spickules of glass fibre projecting from the edge of the laminate.	None	None	Reportable	Process side will be molded apart from overlay. On outside grind spickules off before painting.
Exposed cut edge	An edge of previously cut laminate.	None	None	Non-reportable	Cover with 1.2 kg/m^2 CSM plus surface tissue reinforced layer extending at least 25 mm from the cut edge.
Foreign matter	Any substance other than glass in the laminate.	None	None if it affects the properties of the laminate	Reportable	To be agreed, e.g. treat as a pit.
Pits	A depression in the surface of the laminate not covered with resin.	Max. 3 mm dia. × 0.5 mm deep	Max. 3 mm dia. × 1.5 mm deep	Reportable	Grind out, cover with 1.2 kg/m^2 CSM plus surface covers as for blisters.
Scores	A shallow groove on the surface of the laminate.	Max. 0.2 mm deep	Max. 0.5 mm deep	Non-reportable	Cover with resin.
Surface porosity	Pin-prick holes in the laminate surface.	None	None	Reportable	Grind and cover with 1.2 kg/m^2 CSM plus surface covers as for blisters.
Wrinkles	Wavy surface in laminate.	Max. deviation 20 % of wall thickness, but not exceeding 3 mm	Max. deviation 20 % of wall thickness, but not exceeding 4.5 mm.	Non-reportable	Grind and cover with 1.2 kg/m^2 CSM plus surface covers as for blisters.
Sharp discontinuity	Rapid change in section (assume steeper gradient than 1 : 6)	Max. 0.5 mm (see also **10.1.4**)	Max. 1 mm	Non-reportable	Smooth out with chopped glass and resin and overlay with 1.2 kg/m^2 CSM plus surface covers as for blisters.

Appendix H Inspection

At all stages all materials used should be identifiable against certificates of origin.

Visual inspections should be carried out at all stages during manufacture, particularly after completion of manufacture of pipes and fittings but before shop jointing of these into assemblies.

The recommended inspection stages and requirements are:

a) **Before manufacture commences**

Requirements: Assessment of procedure test pieces in accordance with Appendix F.

b) **During manufacture of pipe and fittings**

Requirements: Visual inspection of quality of workmanship on a random basis.

c) **When pipes, stub flanges, fittings and other items are set ready for jointing in shop or on site when the contract involves erection**

Requirements: Inspection of preparation for jointing, rigidity and accuracy of assembly as follows.

1) When the pipework has been erected and set ready for site jointing.

Requirements: Check that supports are correctly installed and that unintentional strain is not imposed on pipework.

2) When joints are completed but before application of pigmented coating.

Requirements:

i) Visual inspection of complete joints including visual inspection of bore whenever practicable.

ii) Visual inspection of any repairs carried out during manufacture.

3) When pipework is pressure or vacuum tested.

Requirements:

i) Visual inspection of all pipework and joints.

ii) Inspection of all repairs.

4) When manufacture is complete.

Requirements: Check on dimensional accuracy and cleanliness.

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