

Code of practice for

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

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- British Plumbing Fittings Manufacturers' Association
- British Valve and Actuator Manufacturers' Association
- Department of the Environment (Building Research Establishment)
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- Department of the Environment (Property Services Agency)
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- Plastics Land Drainage Manufacturers' Association
- Royal Institute of Public Health and Hygiene
- Society of British Gas Industries
- Water Authorities Association
- Water Companies Association
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- 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.

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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 $-30\text{ }^{\circ}\text{C}$ to $+110\text{ }^{\circ}\text{C}$ 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_a

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

1.2.5

laminate¹⁾

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	F_s	factor of safety
A_σ	stress range during a fatigue cycle	G	length of the end of a reducer
b	coefficient for linear regression line	h	internal diameter of a loose backing flange
B	length of one leg of a 90° bend	H	external diameter of a loose backing flange
c	constant for a linear regression line	I	second axial moment of area (about an axis through the centroid normal to the axis of the pipe)
C	length of one leg of a bend of other than 90°	J	distance between stiffening rings on a pipe
d	internal diameter of the small end of a reducer	J_{B1}	spacing between adjacent branches on a pipe-work system applicable to the internal diameter of the respective branches
D	internal diameter of the large end of a reducer	J_{B2}	
D_i	internal diameter of a pipe or fitting	J_s	length of a (straight) shell contributing to the effect of a stiffening ring
D_{iB}	internal diameter of the branch of a tee	k	factor to compensate for the thermal effects of process gases or liquids respectively
D_{iB1}	internal diameters of adjacent branches on a pipework system (see Figure D.1 and Figure D.2)	K_n	fatigue factor
D_{iB2}		L	span (of supported pipework) [also used as a prefix for reference laminate numbers — see Table 5.1]
D_{iM}	internal diameter of the main of a tee	L_B	length of overlay along a branch
D_{na}	diameter of the neutral axis of a stiffening ring on a pipe	L_{OVL}	length of overlay (for a joint)
D_o	outside diameter of pipe	L_2	socket depth (for a cemented joint) (for a pressure application)
D'	outside diameter of a stub flange	m	pressure stress multiplier
E	modulus of elasticity of a (flange) material	M	applied bending moment (for testing prototype flange designs)
E_{LAM}	modulus of elasticity of a laminate	M_i	maximum in-plane bending moment (on a bend)
E_{LAMx}	modulus of elasticity of a reference laminate in the longitudinal direction	M_o	maximum out-of-plane bending moment (on a bend)
$E_{LAM\phi}$	modulus of elasticity of a reference laminate in the circumferential direction	M_S	torsional moment
E_2	distance from the axis of the branch of a flanged tee to the end of the main	n	number of stress cycles during design life
E_3	distance from the mouth of the branch of a flanged tee to the bore of the main	n_f	number of fatigue test cycles to failure
f_N	anchor load	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	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
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	X_x	unit modulus of glass reinforcement type "x"
S_M	length of a main pipe end from a branch pipe bore	X_{LAM}	laminate unit modulus
S_s	lap shear strength	$X_{LAM d}$	design laminate unit modulus
SIF_b	stress intensification factor for a bend	$X_{LAM x}$	laminate unit modulus in the longitudinal direction
SIF_{Bi}	in-plane branch stress intensification factor	$X_{LAM \phi}$	laminate unit modulus in the circumferential direction
SIF_{Bo}	out-of-plane branch stress intensification factor	y_1	power for the pipe factor of a bend as a function of flexibility factor
SIF_T	stress intensification factor for a tee	y_2	power for the pipe factor of a bend as a function of stress intensification factor
SIF_{xi}	longitudinal SIF under in-plane bending	y_3	power for the pipe factor of a tee as a function of stress intensification factor
SIF_{xo}	longitudinal SIF under out-of-plane bending	y_4	power for the pipe factor of a tee as a function of pressure stress multiplier
$SIF_{\phi i}$	circumferential SIF under in-plane bending	ℓ	linear thermal expansion coefficient
$SIF_{\phi o}$	circumferential SIF under out-of-plane bending	1	coefficient for the pipe factor of a bend as a function of flexibility factor
t	thickness of the laminate	2	coefficient for the pipe factor of a bend as a function of stress intensification factor
t_d	design thickness of the reference laminate	3	coefficient for the pipe factor of a tee as a function of stress intensification factor
t'	thickness of a backing flange	4	coefficient for the pipe factor of a tee as a function of pressure stress multiplier
t_B	thickness of the wall of the branch on a tee, adjacent to the main	β	function of ℓ to relate pressure induced strain to thermally induced strain
t_{CSM}	thickness of a (model) pipe of CSM construction	γ	correction factor for the effect of internal pressure on flexibility factor
t_M	thickness of the reference laminate(s) of the main of a tee	δ_x	correction factor for the effect of internal pressure on longitudinal SIF
T_a	ambient temperature	$\delta\phi$	correction factor for the effect of internal pressure on circumferential SIF
T_p	process temperature	Δ	incremental change in a quantity (e.g. ΔT — see 7.2.2)
ΔT_d	design temperature change	ϵ_d	design strain
ΔT_e	equivalent temperature change	ϵ_r	resin fracture strain
u	ultimate tensile unit strength	ϵ_{xp}	longitudinal strain induced by internal pressure
u_x	ultimate tensile unit strength in the longitudinal direction	$\epsilon_{(10 E 7)}$	predicted strain to cause failure after 10^7 cycles (of a tensile fatigue test)
u_ϕ	ultimate tensile unit strength in the circumferential direction	ϵ_ϕ	circumferential strain
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)		

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
$\kappa_{s \text{ CSM}}$	flexibility factor of a straight CSM pipe of matching $X_{\text{LAM d}}$ 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
σ_ϕ	circumferential stress
$\sigma_{\phi b}$	circumferential bending stress

$\sigma_{\phi p}$ circumferential stress induced by internal pressure at a tee

$\sigma_{(10^7)}$ 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.

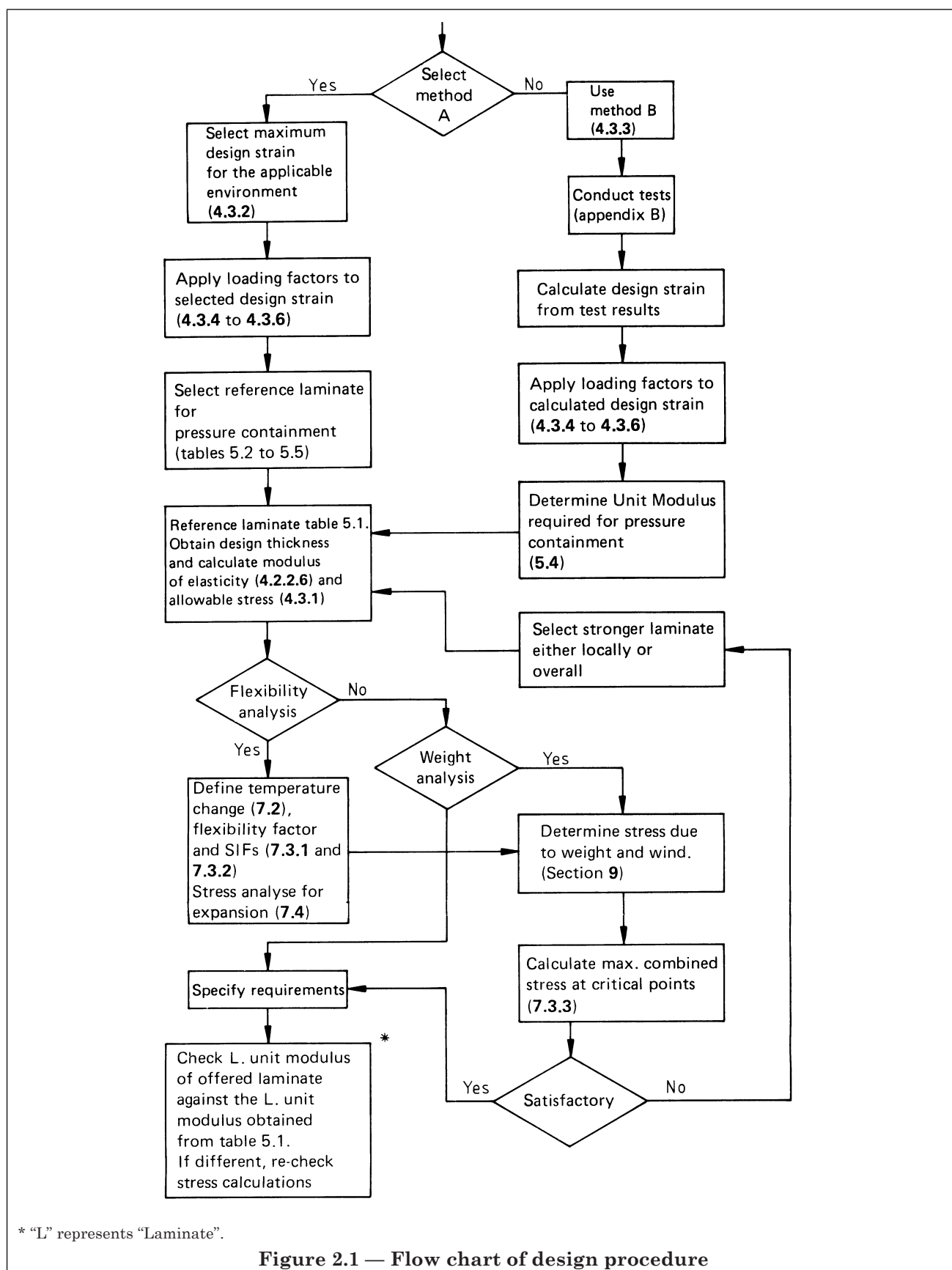


Figure 2.1 — Flow chart of design procedure

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.C.R. 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 ).

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
Polyester and epoxide	Chopped strand mat	N/mm width (per kg/m ² glass) 200	N/mm width (per kg/m ² glass) 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 $\pm 55^\circ$ 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:

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

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/m² glass)];

W_x is the mass of glass reinforcement per unit area (in kg/m²) 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:

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

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:

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

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.

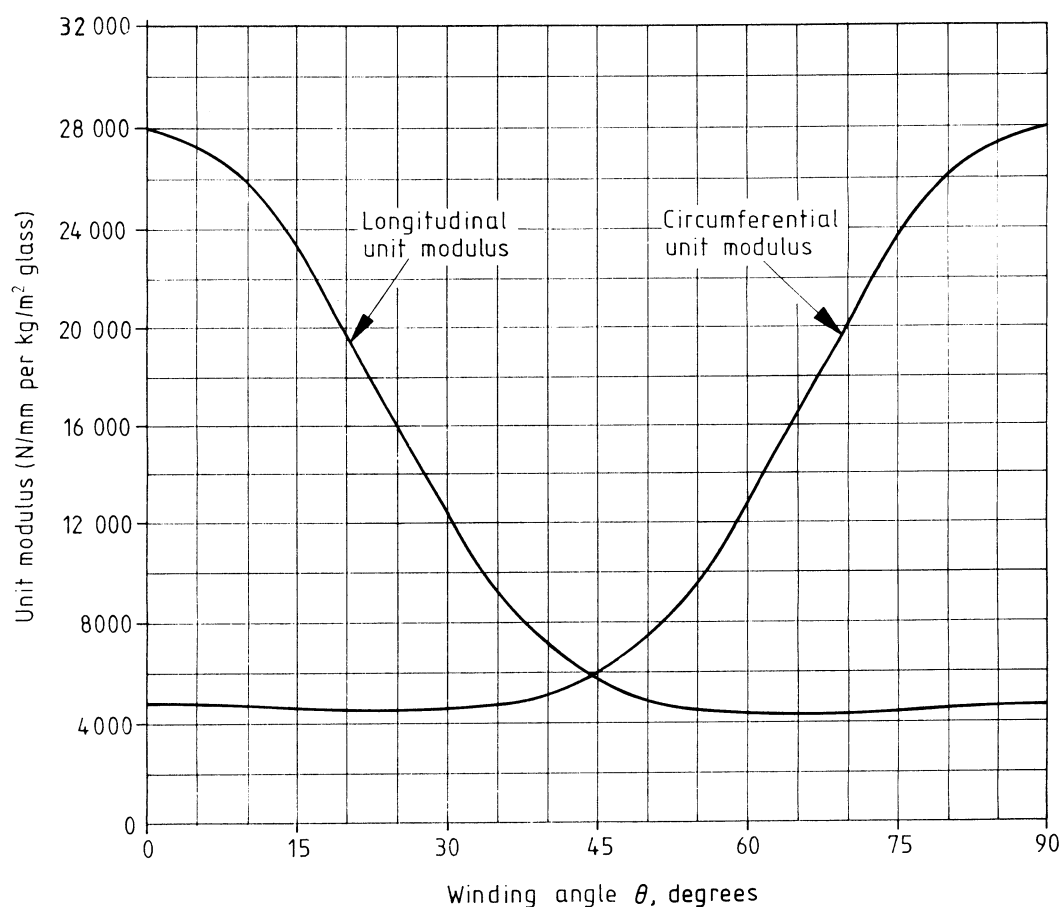
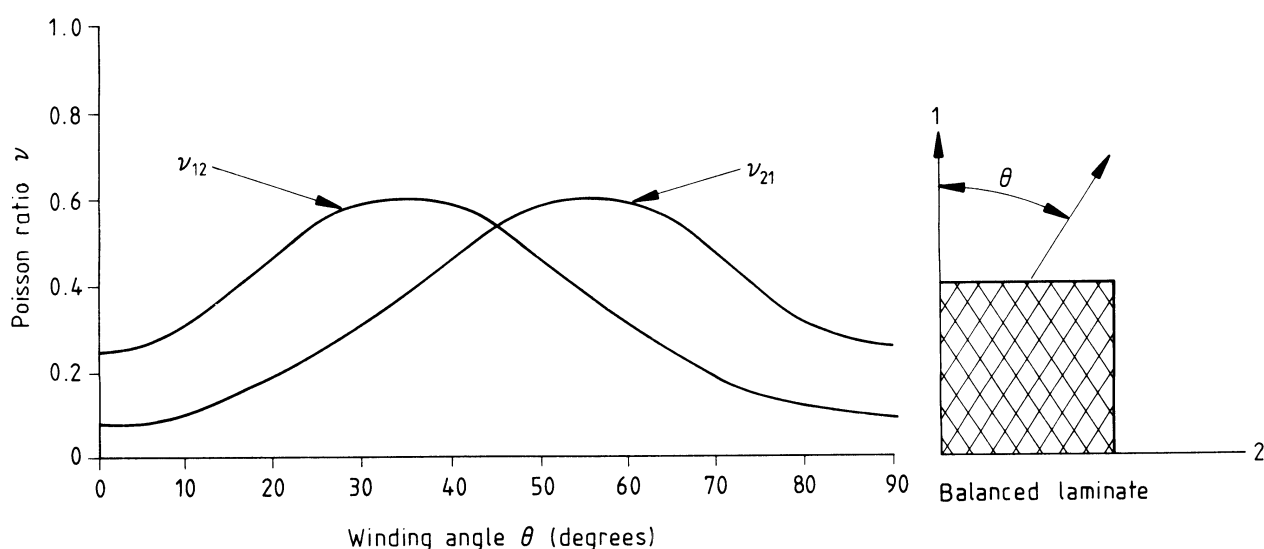


Figure 4.1 — Unit modulus/winding angle



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.

$$K_n = 1 + 0.25(A_\sigma/\sigma_n) (\log_{10}(n) - 3) \quad (4.4)$$

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:

$$\epsilon_d \leq 0.1 \epsilon_r \quad (4.5)$$

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 $\pm 15^\circ$ and $\pm 75^\circ$ 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.

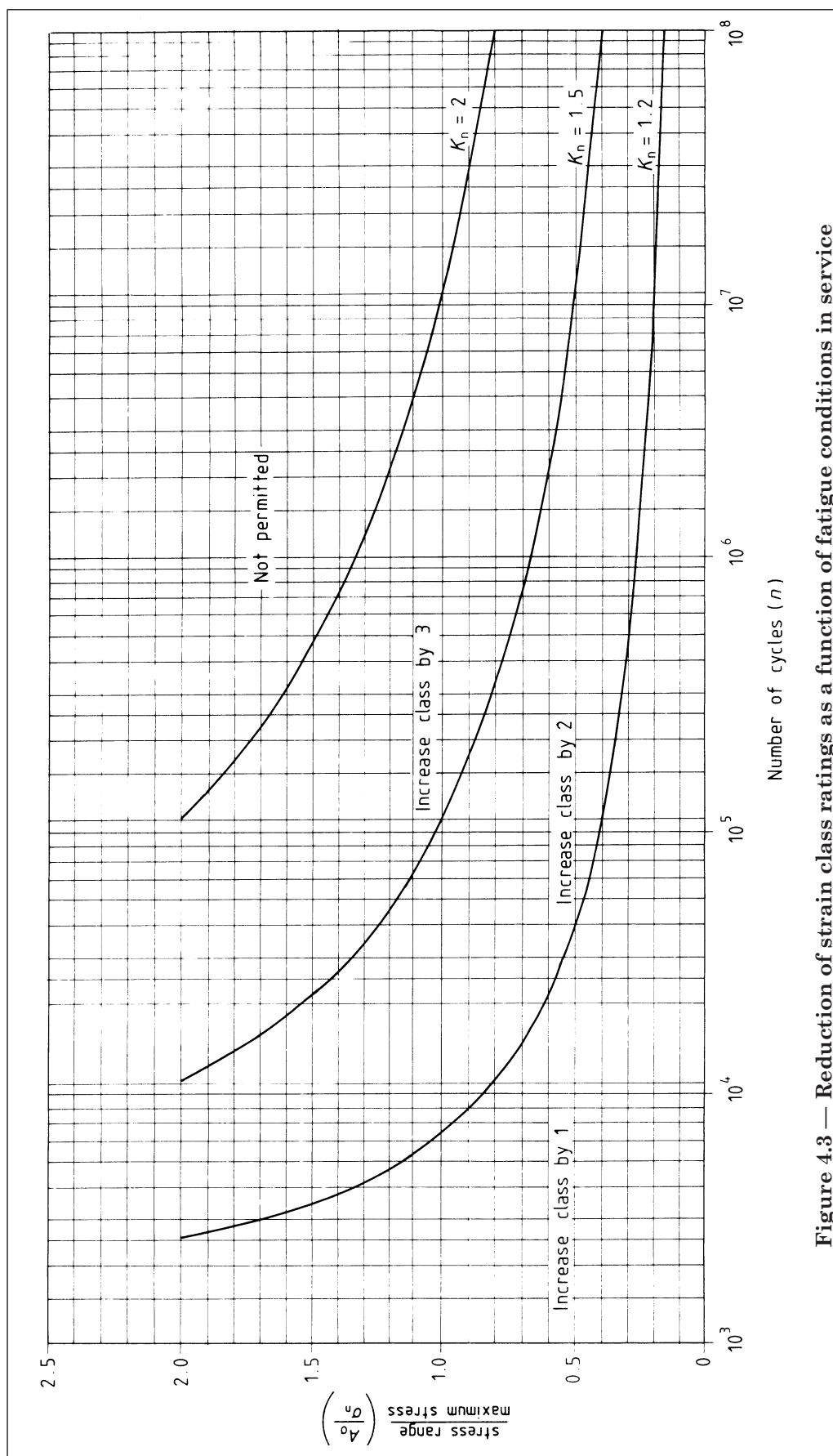


Figure 4.3 — Reduction of strain class ratings as a function of fatigue conditions in service

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 $X_{\text{LAM d}}$ should be calculated in accordance with 5.4.

A reference laminate with a laminate unit modulus that is equal to or greater than $X_{\text{LAM d}}$ 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 bars³⁾:

1, 2½, 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:

- 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;
- 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:

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

- 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.

- Laminate reference L25 to L30:

$$4.0 \leq (\text{CSM:WR})$$

- Laminate reference L40 to L100:

$$6.0 \geq (\text{CSM:WR}) \geq 2.5$$

- Laminate reference L120 to L350:

$$2.2 \geq (\text{CSM:WR}) \geq 1.1$$

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.

- 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 $\pm 55^\circ$.

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 = 10⁵ N/m² = 10⁵ 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:

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

where

$X_{\text{LAM d}}$ 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 $X_{\text{LAM d}}$.

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 $\pm 55^\circ$, the thickness should be calculated using a thickness value of 0.75 mm per kg/m² 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	2½	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	2½	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.