

Specification for design and construction of ferrous piping installations for and in connection with land boilers

Calcul et construction des installations de conduites en métaux ferreux pour chaudières
— Spécifications

Bauart und Konstruktion von Eisenrohrleitungssystemen für ortsfeste Heizkessel

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Foreword

This British Standard, first published in 1938 and subsequently revised in 1942, 1954, 1967, 1975, 1986 and 1990, has been prepared under the direction of the Pressure Vessel Standards Policy Committee. It supersedes the 1990 edition which is withdrawn.

This British Standard forms one of a series for boiler installations, the others in the series being:

BS 1113 Specification for design and manufacture of water-tube steam generating plant (including superheaters, reheaters and steel tube economizers)

BS 2790 Specification for design and manufacture of shell boilers of welded construction

For information on the materials and the standard sizes of steel pipes applicable to this standard, reference should be made to the following standards.

BS 1387 Specification for screwed and socketed steel tubes and tubulars and for plain end steel tubes suitable for welding or for screwing to BS 21 pipe threads

BS 3600 Specification for dimensions and masses per unit length of welded and seamless steel pipes and tubes for pressure purposes

BS 3601 Specification for carbon steel pipes and tubes with specified room temperature properties for pressure purposes

BS 3602 Specification for steel pipes and tubes for pressure purposes: carbon and carbon manganese steel with specified elevated temperature properties

Part 1 Specification for seamless and electric resistance welded including induction welded tubes

Part 2 Specification for longitudinally arc welded tubes

BS 3604 Steel pipes and tubes for pressure purposes: ferritic alloy steel with specified elevated temperature properties

Part 1 Specification for seamless and electric resistance welded tubes

Part 2 Specification for longitudinally arc welded tubes

BS 3605 Austenitic stainless steel pipes and tubes for pressure purposes

Part 1 Specification for seamless tubes

Integral piping for water-tube boilers as determined in the scope and definition clauses of BS 1113 is excluded from this standard and is dealt with in BS 1113.

This 1993 edition incorporates all technical changes up to and including Amendment No. 4 (15 Dec 1992) associated with the 1990 edition. Changes of significance in these amendments have included the development of the following:

- (a) matching of pipe bores and outside diameters for butt welding;
- (b) changes to the hydrostatic test;

(c) issue of appendices for flexibility, evaluation of stresses in branches subject to moment load, and design by analysis;

(d) issue of enquiry cases for the use of butt welding pipe fittings, and testing of pipe bends.

In this standard pressures are expressed as 'gauge' unless otherwise stated.

Fluid pressure is expressed in bar except in the case of calculations where N/mm^2 is used. $1 \text{ bar} = 0.1 \text{ N/mm}^2 = 100 \text{ kPa}$.

A format has been adopted that will facilitate amendment. It is intended to keep this standard up to date by the issue of replacement or additional pages when necessary. Each replacement or added page will carry an issue number (with date) indicating its relationship to the original issue of this standard, the pages of which are marked 'Issue 1'. For example:

Issue 1 will indicate an original page of, or one that has been added to, the original issue of this standard and has not been amended since insertion;

Issue 2 will indicate a first amendment of either an original page or an added page;

Issue 3 will indicate a second amendment of either an original page or an added page.

Side-lining on replacement pages will indicate that changes of technical or reference significance have been made at that point.

This British Standard sets forth engineering requirements deemed necessary for the design and construction of ferrous pipework for and in conjunction with land boilers.

Because of the wide range of pipes and piping installations that may be designed and manufactured in accordance with this standard, general guidance has been given on some aspects with specific requirements being for agreement between the parties concerned according to the particular design and manufacturing details. The purpose of this standard, however, is unchanged from previous editions.

It has been assumed in the drafting of this British Standard that the execution of its provisions is entrusted to appropriately qualified and experienced people.

The purchaser is recommended as an aid to demonstrating the pipework supplier's capability of achieving the required quality level, to specify in his contract, that the manufacturer operates a quality system in compliance with the appropriate Parts of BS 5750.

This standard is included in the list of 'Standards significant to Health and Safety at Work' published by the UK Health and Safety Executive (HSE)* and is also referred to by HSE in giving guidance.

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

* Health and Safety Executive, Baynards House, 1 Chepstow Place, London, W2 4TF.

Section one. General

1.1 Scope

This British Standard specifies requirements for the design and construction, including materials and design parameters, workmanship, inspection and testing, for ferrous pipes and piping installations for and in connection with land boilers.

This standard applies to the following.

- (a) The ferrous pipework connecting steam generating plant to engine, turbine or industrial plant and all ancillary steam and water pipework in connection therewith.
- (b) The pipes and pipe fittings forming parts of the installations described in (a) for:
 - (1) pipes of any bore, where the pressure exceeds 3.5 bar; and
 - (2) pipes over 250 mm bore for steam at pressures up to and including 3.5 bar.

NOTE 1. The term 'pipe fitting' used in this standard includes tees, elbows and special components, but excludes valves and everything covered by BS 759 and BS 6759.

- (c) Ferrous pipes and piping installations constructed in materials used up to the design temperature limits given in table 3.2.

This standard does not apply to the component parts of the boiler unit or to integral piping which are dealt with in BS 1113.

NOTE 2. Attention is drawn to the safety requirements specified in section seven of BS 1113 : 1992 for certain valves and fittings which may require installation in piping systems beyond the scope of BS 1113.

NOTE 3. The titles of the publications referred to in this standard are listed on the last page.

1.2 Interpretation

If any ambiguity is found or doubt arises as to the meaning or effect of any part of this standard or as to whether anything ought to be done or omitted in order to comply with this standard in full, the question shall be referred to the Piping Systems Technical Committee (PVE/10) of the British Standards Institution, whose interpretation of the requirements of this standard upon the matter at issue will be given free of charge and shall be accepted as final and conclusive. Parties adopting this standard for the purposes of any contract shall be deemed to have accepted this provision unless by their contract they either expressly exclude it or else include an arbitration provision extending the interpretation of this standard; however, this provision shall be limited to interpretation and shall not confer upon the committee any power or jurisdiction to adjudicate upon the contractual rights or duties of any person under a contract except in so far as they may necessarily be affected by the interpretations arrived at by the committee.

Findings or rulings of the committee upon all enquiries, including matters of interpretation, that are of sufficient

importance for both enquiries and replies to be made public as soon as possible will be published in an enquiry-reply form for inclusion in the BS 806 ring-binder as Enquiry Cases. Their availability will be notified in *BSI News*.

After taking into account any public comment thereon, Enquiry Cases will be incorporated, if appropriate, into the standard either by amendment or in the course of the next convenient annual updating.

1.3 Definitions and prime symbols

1.3.1 Definitions

For the purposes of this British Standard the following definitions apply.

1.3.1.1 purchaser. The organization or individual who buys the finished piping installation for its own use or as an agent for the owner.

1.3.1.2 manufacturer. The organization that designs, fabricates and erects the piping installation in accordance with the purchaser's order. The design, fabrication and erection functions may be carried out by separate organizations.

1.3.2 Prime symbols

The prime symbols used in the equations in this British Standard are defined as follows.

- D mean outside diameter* of the pipe (in mm)
- d mean inside diameter* of the pipe (in mm). This should not be confused with nominal size, which is an accepted designation associated with outside diameters of standard rolling sizes.
- t_f minimum thickness of the pipe calculated by the appropriate equation (in mm)
- t_b minimum thickness of the pipe before bending, i.e. t_f + bending allowance (in mm)
- t_m minimum thickness of the branch or main at the branch position (in mm)
- t mean thickness based on limiting thickness tolerances of the ordered pipe (in mm)
- T design temperature (in °C)
- p design pressure (in N/mm²)
- f maximum permissible design stress (in N/mm²)
- P_t hydraulic test pressure (in N/mm²)

1.4 Information and requirements to be agreed and to be documented

1.4.1 Information to be supplied by the purchaser

The following information shall be supplied by the purchaser and shall be fully documented. Both the definitive requirements specified throughout this standard and the documented items shall be satisfied before a claim of compliance with the standard can be made and verified.

* The mean diameter for the purposes of calculation is the diameter midway between the maximum and minimum diameters possible using tolerances specified in the tube manufacturing specifications.

(a) The design pressure and temperature determined in accordance with section two including any exceptional conditions (see note 2 to 2.3).

NOTE. It is the responsibility of the purchaser to ensure that the installation is operated within the limits determined in accordance with section two.

(b) The name of the Inspecting Authority, if any.

(c) Whether or not the purchaser or his representative desires to witness any tests.

(d) Whether or not the purchaser desires to receive any test certificates.

(e) Any special limitations, e.g. with respect to composition, heat treatment, inspection (test category) that are required in relation to the particular end use of the pipes/piping system (see 3.1.1).

(f) The pipe internal surface conditions required before erection, if not in accordance with 5.8.

1.4.2 Requirements to be agreed and documented

1.4.2.1 General. The items listed in 1.4.2.2 and 1.4.2.3 to be agreed shall be fully documented. Both the definitive requirements specified throughout this standard and the documented items shall be satisfied before a claim of compliance with this standard can be made and verified.

NOTE. Users of this standard should appreciate that a number of items of agreement, i.e. those listed under 1.4.2.3, cannot be agreed/documented at the time of placing the contract or order for the pipework and do not necessarily apply in every case; they make provisions for individual agreements that may be necessary during the manufacturer's operations to deal with certain practical eventualities. It is important to distinguish these items (1.4.2.3) from those listed in 1.4.2.2, which need to be agreed and documented when the contract or order is placed.

1.4.2.2 Requirements to be agreed and documented at the contract or order stage. The following items, as appropriate, shall be agreed and documented.

(a) Design lifetime of piping installations (see 2.8).

(b) Basis for extrapolation of values of design temperature (see general note (b) to table 3.2).

(c) Increased design stresses for certain alloy steels (see note 6 to table 3.2).

(d) Maximum values for the forces and moments that may be applied to the equipment to which the pipes/piping installation are/is to be connected (see 4.11.1).

(e) Waiver of the hydraulic test after erection for Class II welded systems in cases where the pipe joints are non-destructively examined in accordance with 6.3.4 and the requirements of 6.1.1 have been complied with before erection (see 6.2.2).

1.4.2.3 Requirements to be agreed and documented during the manufacturer's operations. The following items, as appropriate, shall be agreed and documented.

(a) The use, for pressure parts, of materials *not* covered by the British Standards referred to in table 3.1.2 (see 3.1.2.1(b)) and whether elevated temperature yield point or proof stress properties related to tests in accordance with BS 3688 are not required for such materials (see 3.1.2.2.5).

(b) The heat treatment condition for materials not covered by table 3.1.2, if an alternative to the condition appropriate to the nearest equivalent British Standard material is required (see 3.1.2.2.7).

(c) The use of cast steel straight pipes and bends, including the areas to be inspected and the inspection techniques to be adopted (see 4.5).

(d) The form of reinforcement for branch connections to mains, if those specified in 4.8.5 and 4.8.6 cannot be provided (see 4.8.3).

(e) The use of welds in accordance with processes other than those covered by the standards specified in 5.3.1 (a) (see 5.3.1(b)).

(f) Waiver of the hydraulic test for wrought steel pipes where the only work of manipulation and fabrication has been the welding of minor attachments subject to internal pressure (see 6.1.3(b) (2)).

(g) The carrying out of non-destructive examination before stress relief in the case of branch, socket and attachment welds in carbon, carbon manganese, grade 620 and grade 621 alloy steels (see 6.3.2.2(b)).

(h) The appropriate level and category of certification of personnel for non-destructive examination, where not in terms of those obtained from an agreed nationally accredited certification scheme (see 6.3.2.3).

Section two. Design pressures and temperatures

2.1 General

For the purposes of this British Standard, the pressures and temperatures for which pipes and pipe fittings are designed shall be as specified in 2.2 to 2.7.

2.2 Design pressure for steam piping

2.2.1 The design pressure for piping downstream of the steam stop valve of the boiler shall be either:

- (a) the design pressure of the boiler in the case of boilers complying with BS 2790 or the maximum permissible working pressure in the case of plant complying with BS 1113; or
- (b) for piping whose design stresses are time-dependent (see table 3.2 and B.4) and the total capacity of the safety valves on the superheater is not less than 20 % of the evaporative capacity of the boiler, the lowest pressure at which any superheater safety valve is set to lift.

2.2.2 In reheat systems where the design stresses of the piping are time-independent, the design pressure shall be the highest pressure at which any safety valve on the reheat system is set to lift. When no safety valves are mounted at the reheater inlet, the design pressure of the reheater inlet piping shall be the highest pressure at which any reheater outlet safety valve is set to lift, increased to take account of the pressure drop through the reheater corresponding to the most severe conditions of operation.

2.2.3 In reheat systems where the design stresses of the piping are time-dependent (see table 3.2 and B.4), the design pressure shall be the lowest pressure to which any safety valve on the reheat system is set to lift. When no safety valves are mounted at the reheater inlet, the design pressure of the reheater inlet piping shall be the lowest pressure at which any reheater outlet safety valve is set to lift, increased to take account of the pressure drop through the reheater corresponding to the most severe conditions of operation.

2.2.4 For reduced pressure systems, it is permissible for the pressure to be controlled at a value below that in the originating piping system by a reducing valve or by the pressure drop across a fixed restriction such as an orifice or the blading of the turbine.

Where a protective device consisting of a safety valve or valves or a suitable appliance for automatically cutting off the supply of steam at a predetermined pressure is fitted, the design pressure for piping systems, whose design stresses are time-independent, (see table 3.2 and B.3) shall be that to which the pressure under the most arduous condition is limited by the proper operation of such a device. Where similar provisions are made on piping systems whose design stresses are time-dependent (see table 3.2 and B.4), the design pressure shall be the highest controlled operating pressure, provided that the average pressure in any one

year does not exceed that pressure and that the fluctuations in controlled pressure at no time exceed the design value by more than 20 %.

Where no protective device is fitted, the design pressure shall be the greatest pressure therein attainable under the most arduous operating condition, i.e. with the originating piping system operating at its design pressure, with the upstream valves (including any reducing valves or restrictions) fully open, and with the downstream valves (other than non-return valves) fully closed.

The relieving capacity of safety valves (as determined in accordance with BS 759 and BS 6759) fitted downstream of pressure reducing valves shall be such that the operating pressure limitation shall not be exceeded by more than 10 % (see BS 6759 : Part 1) if the reducing valve fails in the open position with the downstream valves (other than non-return valves) fully closed.

2.3 Design temperature for steam piping

The design temperature for steam piping shall be:

- (a) for main steam piping, the rated temperature at the superheater outlet;
- (b) for reheated steam piping, the rated temperature at the reheater outlet;
- (c) for other steam piping, the highest rated temperature at the higher temperature end of the pipes.

In all cases the following limitations shall be satisfied in service at design pressure conditions:

- (1) the average temperature during any one year of operation does not exceed the design temperature; and
- (2) for systems having a rated temperature of 380 °C and below, fluctuations in temperature do not exceed the design temperature by more than 10 %; or
- (3) for systems having rated temperature above 380 °C:
 - (i) normal fluctuations in temperature do not exceed the design temperature by more than 8 °C; and
 - (ii) abnormal fluctuations in temperature do not exceed the design temperature by more than 20 °C for a maximum of 400 h in any one year or 30 °C for a maximum of 100 h in any one year or 40 °C for a maximum of 60 h in any one year.

NOTE 1. Excursions above these limits may shorten the overall life of the installation.

Where the maximum temperature will exceed these limits, the design temperature shall be increased by the amount of the excess.

NOTE 2. The limits in (1), (2) and (3) represent realistic figures for modern control systems and plant meeting normal load demands. It is the responsibility of the purchaser to advise the manufacturer, before design of the plant is commenced, of any circumstances that could prevent these limits being complied with (see 1.4.1(a)). It is the responsibility of the purchaser also to ensure that the installation is operated within these or any other agreed limits.

2.4 Design conditions for feed piping

2.4.1 Design temperature

The design temperature shall be the rated temperature of the section of pipe under consideration.

2.4.2 Design pressure

2.4.2.1 Pump suction. The design pressure shall be the maximum pressure to which the pipework may be subjected.

2.4.2.2 Pump discharge. The design pressure shall be the pump pressure when handling cold water at 15 °C at full rated speed against a closed valve. No additional allowance to the design pressure need be made for pump overspeed unless this exceeds full rated speed by more than 10 % but where the speed exceeds this limit, the design pressure shall be increased by the effect of the excess in overspeed over 10 %.

Specific allowance shall be made for the effects of water hammer if the results of pressure surges exceed the design pressure by more than 20 %.

Where a safety valve or other protective device is fitted to restrict the pressure to a lower value than the closed valve pressure as defined in this subclause, the design pressure shall be the highest set pressure thereof.

2.5 Design pressure for blowdown and drain systems

2.5.1 The design pressure upstream and including any shut off valve, control valve, or trap shall be that of the upstream component to which they are connected, but not less than 7 bar if the system is handling a flashing liquid.

Where a control or restriction orifice is fitted, then this shall be considered as a control or shut off valve.

2.5.2 The design pressure downstream from the last shut off valve, control valve, trap or restrictor treated as a control in accordance with **2.5.1** shall also comply with **2.5.1**, except that where:

- (a) the downstream pipe has a cross-sectional area of not less than 2.5 times the combined simultaneous areas that can discharge into it; and
- (b) further that this downstream pipe discharges freely into an adequately vented receiver;

then the design pressure may be taken as one-half of the upstream pressure specified in **2.5.1** but shall not be less than 7 bar if the system is handling a flashing liquid.

2.5.3 The design pressure of a blowdown vessel or a drain vessel shall be the maximum pressure that can be imposed upon it in operation but not less than the lower value of 7 bar or 25 % of the maximum permissible working pressure of the boiler. The vessel, and vessel component thicknesses however, shall also be capable of sustaining the mechanical loads imposed thereon (see **4.12.6**).

NOTE. Attention is drawn to Guidance Note PM60 'Steam boiler blow down systems'.

2.6 Design temperature for blowdown and drain systems

2.6.1 The design temperature for systems described under **2.5.1** shall be that of the upstream component.

NOTE. Where the design stress is time-dependent, the design lifetime will be the same as that of the upstream component except where a control or restriction orifice is fitted between the last valve and the drain discharge point when for that section of pipe between the last valve and the orifice a reduced design lifetime may be used if the drain is used intermittently.

2.6.2 The design temperature for systems described under **2.5.2** shall be the greater of:

- (a) the design temperature T (in °C) determined from:

$$T = \frac{T_S - 41}{1.15} \quad (1)$$

where

T_S is the design temperature (in °C) of the component from which the drain or blowdown system originates;

- (b) the saturation temperature at the design pressure of the system derived from **2.5.2**.

NOTE. The reduced time design life for intermittent use is also applicable to the systems covered by this subclause.

2.6.3 The design temperature T (in °C) of a blowdown vessel, or drain vessel, or atmospheric vent shall be determined from:

$$T = \frac{T_S - 41}{1.15} \quad (2)$$

where

T_S is the design temperature (in °C) of the component from which the drain or blowdown system originates.

The design temperature shall neither be higher than the highest design temperature of any pipe discharging into the vessel nor lower than saturation temperature at the vessel design pressure.

2.7 Design conditions for safety valve discharge piping

2.7.1 The design pressure of the discharge piping shall be the maximum pressure which can be imposed upon it, but in no case less than 3.5 bar.

NOTE. For methods of calculating the design pressure, see appendix A.

2.7.2 The capacity of the safety valve for the purpose of calculation shall be 1.11 times the certified discharge capacity as defined in BS 6759 : Part 1.

NOTE. The discharge piping system should be such as not to create a built up back pressure, measured at the safety valve outlet connection, of more than 12 % of the set pressure of the safety valve, subject to a maximum of 17 bar. If the discharge

pipng system gives rise to a higher built up back pressure, the design should be referred to the safety valve manufacturer for agreement that the safety valve performance will not be adversely affected.

2.7.3 The design temperature T (in °C) of safety valve discharge piping shall be:

$$T = \frac{T_S - 41}{1.15} \quad (3)$$

where

T_S is the temperature (in °C) of steam at the safety valve body inlet.

NOTE. For the purpose of calculating the thermal expansion of the discharge pipe, a temperature 25 °C higher than this design temperature should be assumed.

2.8 Design lifetime

An appropriate design lifetime shall be agreed between purchaser and manufacturer (see 1.4.2.2(a)) for

installations whose design temperature is such that the nominal design stress given in table 3.2 is time-dependent.

NOTE 1. The basis of design in this standard is that no component remains in service after its operational hours have exceeded the design lifetime. However, experience has demonstrated that components designed in accordance with this standard can be expected to exceed their design lifetime and reference may be made to PD 6510 for procedures for assessing their fitness for service and whether the life could be extended.

Components of certain alloy materials designed on the basis of increased design stress value (see note 2) shall be identified on the drawings and listed by the manufacturer. Continued service reviews shall be instituted at not later than two-thirds of the design lifetime.

NOTE 2. The design stress values of certain alloy materials may be increased by agreement between purchaser and manufacturer: see note 6 to table 3.2.

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Section three. Materials and maximum permissible design pressures, temperatures and stresses

3.1 Materials

3.1.1 General

The selection of the materials of construction for piping installations shall take into account the suitability of the material with regard to weldability, forming, etc. and to the conditions under which they will eventually operate.

Any special limitations, e.g. with respect to composition, heat treatment and inspection (test category), that may be required in relation to the particular end use of the material shall be stated by the purchaser at the time of enquiry and order (see 1.4.1(e)).

3.1.2 Materials/components for pressure parts

3.1.2.1 General. Each of the materials/components selected shall either:

- (a) comply with the appropriate British Standards given in table 3.1.2; or
- (b) by agreement between the manufacturer and the purchaser (see 1.4.2.3(a)) comply with 3.1.2.2.

NOTE. The requirements of this British Standard have been drafted largely on the basis of experience with the materials specified in the British Standards referred to in table 3.1.2; the selection of such materials should therefore be preferred. However, it is accepted that special circumstances may occur in which the selection of materials other than those covered by table 3.1.2 is necessary; the requirements of 3.1.2.2 have been specified to provide a basis for material selection in such circumstances.

3.1.2.2 Materials not covered by table 3.1.2

3.1.2.2.1 The materials shall be covered by a written specification at least as comprehensive as the British Standards listed in table 3.1.2 for the nearest equivalent material. For ferritic steels, the phosphorus and sulphur content shall not exceed 0.05 % (m/m)* each in the ladle analysis.

NOTE. For ferritic steels intended for welding, the upper limit of the carbon range (in the ladle analysis) should not exceed 0.25 % (m/m). Steels with a higher carbon content that are intended for

welding may be used subject to appropriate welding procedures and heat treatment.

3.1.2.2.2 The design stresses shall be determined in accordance with the principles described in appendix B.

3.1.2.2.3 The deoxidation practice shall be appropriate to the type of steel ordered. Semi-killed steel shall be used only for seamless and welded tubes in carbon and carbon manganese steels with an upper limit of the specified tensile strength range of 640 N/mm² and with a thickness not exceeding 100 mm. Rimming steel shall be used only for welded tubes in carbon and carbon manganese steel with an upper limit of the specified tensile strength range of 490 N/mm² and under service temperature conditions of 400 °C or less.

3.1.2.2.4 Minimum specified values for mechanical properties at room temperature shall be proven by means of acceptance tests covering tensile strength, yield stress and elongation.

The specified minimum percentage elongation at fracture referred to a gauge length of $5.65 \sqrt{S_0}$ † shall be appropriate to the type of steel, with a lower limit of 16 % for plates, 15 % for castings and 14 % for tubes and forgings.

The rate of testing and methods of acceptance testing shall be generally in alignment with the appropriate British Standards for similar product forms.

3.1.2.2.5 For all pressure parts, elevated temperature yield point or proof stress properties related to tests in accordance with BS EN 10002-5 shall be specified unless otherwise agreed between the purchaser and the manufacturer (see 1.4.2.3(a)).

Where no elevated temperature yield point or proof stress property values exist or where the material cannot be related to another material for which values exist, property values shall be verified using the procedure described in BS 3920 or shall be established by the recognized standards of other countries.

Table 3.1.2 British Standards covering materials/components for ferrous pipes and piping installations

Steel pipes	Pipe fittings	Iron castings (see note)	Steel castings	Flanges and bolting	Forgings
BS 1387, BS 3601, BS 3602 : Parts 1 and 2, BS 3604 : Parts 1 and 2, BS 3605 : Part 1	BS 143 and 1256, BS 1640, BS 1740, BS 1965 : Part 1, BS 3799	BS 1452 grade 220, BS 2789 grade 420/12, BS 4622, BS 4772	BS 1504	BS 10, BS 1560, BS 4504, BS 4882	BS 1503
NOTE. Grey iron castings, pipes and fittings shall not be used for applications where the design temperature exceeds 220 °C. Ductile iron castings, pipes and fittings shall not be used for applications where the design temperature exceeds 350 °C, see 4.6.					

* Percentage by mass.

† S_0 is the original cross-sectional area of the gauge length of the tensile test specimen (see BS 18).

3.1.2.2.6 Stress rupture properties derived from creep rupture testing shall be specified for materials which will be used in the creep range. The manufacturer of the pipework installation shall be assured by the material supplier that the product supplied is capable of complying with the specified properties by a statement that the manufacturing processes have remained equivalent to those for the steel for which the test results were obtained.

3.1.2.2.7 Materials shall be supplied in heat treated condition appropriate to the nearest equivalent British Standard material unless otherwise agreed between the purchaser and the manufacturer (see **1.4.2.3(b)**).

Electric resistance welded or induction welded tubes shall be used in the as welded condition only where the specified upper limit of tensile strength does not exceed 540 N/mm^2 .

3.1.3 Materials components, for non-pressure parts, not covered by British Standards

For supporting lugs and other attachments welded to pipework, the material shall be of established identity and

shall be of recognized compatibility with the materials/components to which they are attached.

3.2 Maximum permissible design pressures, temperatures and stresses

The pressure and temperature limits within which pipes and pipe fittings of various materials are permitted to be used and the maximum design stress values shall be as given in table 3.2, (see also **1.4.2.2(c)**).

NOTE 1. The design stresses given in table 3.2 have been derived in accordance with appendix B.

NOTE 2. No stresses have been tabulated for pipe complying with BS 1387 or BS 3601 — BW 320. Such pipe up to 150 mm nominal size may be used for pressure not exceeding 21 bar and temperatures not exceeding 260°C provided that it is at least of the medium thickness specified in BS 1387. The pressure and size limit is reduced when the pipe is used with screwed and socketed joints (see table 4.7.4(1)).

NOTE 3. The thickness of cast iron straight pipe and fittings should be in accordance with **4.6**. Where design stresses are required the following may be used:

BS 1452 grade 220: 21 N/mm^2 for temperatures not exceeding 220°C ;

BS 2789 grade 420/12: 84 N/mm^2 for temperatures not exceeding 350°C .

Table 3.2 Design stress values (a) Steel tubes and pipes																							
Material	Tube standard	Method of manufacture	Steel grade	Thickness mm	Values of f (N/mm ²) for design temperatures (°C) not exceeding																	Design lifetime h	Notes
					50	100	150	200	250	300	350	380	390	400	410	420	430	440	450	460	470		
Carbon	BS 3601	ERW	320		130	119	108	97	86	77	71	69	69	68							4		
Carbon	BS 3601	ERW, S S	360	≤ 16 40 65	154 150 143	140 136 131	126 122 119	111 109 107	96	86	79	77	76	75							4		
Carbon	BS 3601	ERW, S S	430	≤ 16 40 65	183 177 170	166 162 156	149 146 143	132 131 129	115	103	95	91	90	89							4		
Carbon	BS 3601	SAW	430	≤ 16 40 65	183 177 170	166 162 156	149 146 143	132 131 129	115											1,4			
Carbon	BS 3602: Part 1	HFS, CFS ERW, CEW HFS, CFS HFS, CFS	360	≤ 16 40 65	153 150 143	139 137 134	125 125 125	117 117 117	111	97	87	82	80	78	77	77	76	69	60	52	44	36	100 000 150 000 200 000 250 000
Carbon	BS 3602: Part 1	HFS, CFS ERW, CEW HFS, CFS HFS, CFS	430	≤ 16 40 65	183 177 170	166 163 161	149 149 149	135 135 135	120	109	101	97	96	95	95	88	79	69	60	52	44	36	100 000 150 000 200 000 250 000
Carbon	BS 3602: Part 1	HFS, CFS	500 Nb		213	204	194	178	163	148	135	129	127	125	121	105	90	77	65	56	48	42	100 000 150 000 200 000 250 000
Carbon	BS 3602: Part 2	LAW	430	≤ 16 40	167 160	158 155	149 149	135 135	120	109	101												
Carbon	BS 3602: Part 2	LAW	490		209	187	165	153	143	131	121												

Table 3.2 Design stress values (continued)
(a) Steel tubes and pipes (continued)

Material	Tube standard	Method of manufacture	Steel grade	Values of f (N/mm ²) for design temperatures (°C) not exceeding																								Design lifetime h	Notes		
				50	100	150	200	250	300	350	400	440	450	460	470	480	490	500	510	520	530	540	550	560	570	580	590			600	610
Alloy	BS 3604 : Part 1	HFS, CFS	591	260 260 260 260 260 255 249 229																								9			
Alloy	BS 3604 : Part 1	HFS, CFS, ERW, CEW	620-440	187	178	169	163	157	128	121	116	112	112	111	111	93	76	62	52	42	33	27	100 000	150 000	200 000	250 000					
Alloy	BS 3604 : Part 1	HFS, CFS, ERW, CEW	621	179	169	158	152	145	116	110	105	101	100	100	93	76	62	52	42	33	27	100 000	150 000	200 000	250 000						
Alloy	BS 3604 : Part 1	HFS, CFS	660	196	190	184	178	161	150	144	139	135	134	133	131	115	100	87	76	66	56	100 000	150 000	200 000	250 000						
Alloy	BS 3604 : Part 1	HFS, CFS	622	183	176	169	163	157	153	149	145	137	135	133	131	118	105	94	82	72	61	53	45	39	34	29	26	2.6			
Alloy	BS 3604 : Part 1	HFS, CFS	762	294	276	259	249	240	232	227	217	206	191	187	173	155	138	122	107	93	80	68	58	48	40	33	100 000	150 000	200 000	250 000	
Alloy	BS 3604 : Part 2	LAW	620	204	192	180	172	165	152	143	141	137																			
Alloy	BS 3604 : Part 2	LAW	621	219	211	203	194	187	177	170	167	163																			
Alloy	BS 3604 : Part 2	LAW	622	207	198	189	183	177	173	168	163	156																			

Table 3.2 Design stress values (continued)																													
(a) Steel tubes and pipes (continued)																													
Material	Tube standard	Method of manufacture	Steel grade	Values of f (N/mm ²) for design temperatures (°C) not exceeding																								Design lifetime h	Notes
				50	100	150	200	250	300	350	400	450	500	520	540	550	560	580	600	620	640	650	660	680	700	720	740		
Austenitic	BS 3605 : Part 1	HFS, CFS, HFM	304 S11	143	127	111	101	95	90	86	81	80																	
Austenitic	BS 3605 : Part 1	HFS, CFS, HFM	304 S31	157	139	121	109	101	97	94	91	88																	
Austenitic	BS 3605 : Part 1	HFS, CFS, HFM	304 S51	157	139	121	109	101	97	94	91	88	86	83	82	82	76	65	55	50	45	38	33	28					
																82	72	61	51	46	42	36	31						
																81	69	58	48	44	40	34	30						
																78	66	55	46	42	38	33	29						
Austenitic	BS 3605 : Part 1	HFS, CFS, HFM	316 S11, S13	150	135	119	110	103	99	94	91	88																	
Austenitic	BS 3605 : Part 1	HFS, CFS, HFM	316 S31, S33	163	146	128	118	111	106	102	98	96																	
Austenitic	BS 3605 : Part 1	HFS, CFS, HFM	316 S51, S52	163	146	128	118	111	106	102	98	96	93	90	89	88	74	58	53	46	35	28	23	19	18				
																85	66	52	46	41	32	25	19	16					
																79	62	48	43	38	29	22	18	15					
																75	58	45	40	35	27	22	18	15					
Austenitic	BS 3605 : Part 1	HFS, CFS, HFM	321 S31	156	144	133	127	121	117	112	110	107																	

Table 3.2 Design stress values (continued) (a) Steel tubes and pipes (concluded)																
Material	Tube standard	Method of manufacture	Steel grade	Values of f (N/mm ²) for design temperatures (°C) not exceeding												
				50	100	150	200	250	300	350	400	450	500	550	600	650
Austenitic	BS 3605 : Part 1	HFS, CFS, HFM	321 S51 (1010)	156	144	133	127	121	117	112	110	107	104	102	102	101
														86	71	57
														49	42	36
														31	24	18
Austenitic	BS 3605 : Part 1	HFS, CFM, HFM	321 S51 (1105)	102	101	93	78	64	49	42	36	32	27	102	101	93
														78	64	49
														42	36	32
														27	25	25
Austenitic	BS 3605 : Part 1	HFS, CFM, HFM	347 S31	100	93	85	71	55	42	35	31	26	22	100	93	85
														71	55	42
														35	31	26
														22	22	22
Austenitic	BS 3605 : Part 1	HFS, CFM, HFM	347 S51	130	116	103	98	93	87	84	82	79	77	76	75	68
														60	55	49
														44	34	26
														29	29	29
Austenitic	BS 3605 : Part 1	HFS, CFM, HFM	347 S51	72	58	52	46	41	35	27				72	58	52
														46	41	35
														35	27	27
														27	25	25
Austenitic	BS 3605 : Part 1	HFS, CFM, HFM	347 S51	163	155	146	138	135	130	124	122	119		163	155	146
														130	124	123
														107	87	71
														52	40	40
Austenitic	BS 3605 : Part 1	HFS, CFM, HFM	347 S51	117	117	116	99	82	66	59	53	47	41	117	112	93
														75	61	54
														48	42	37
														28	22	22
Austenitic	BS 3605 : Part 1	HFS, CFM, HFM	347 S51	116	106	88	72	58	51	45	39	34	25	116	106	88
														51	45	39
														34	25	19
														19	19	19
Austenitic	BS 3605 : Part 1	HFS, CFM, HFM	347 S51	112	102	85	68	55	48	42	37	32	24	112	102	85
														48	42	37
														32	24	19
														19	19	19
Austenitic	BS 3605 : Part 1	HFS, CFM, HFM	347 S51	130	124	123	107	87	71	52	40			130	124	123
														71	52	40
														40	35	35
														35	32	32
Austenitic	BS 3605 : Part 1	HFS, CFM, HFM	347 S51	124	114	93	75	62	46	35				124	114	93
														62	46	35
														35	32	32
														32	32	32
Austenitic	BS 3605 : Part 1	HFS, CFM, HFM	347 S51	118	96	76	62	52	40					118	96	76
														62	52	40
														40	35	35
														35	32	32

(b) Steel castings

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Table 3.2 Design stress values (continued)																														
(b) Steel castings (concluded)																														
Material	Casting standard	Steel grade	Values of f (N/mm ²) for design temperatures (°C) not exceeding																								Design lifetime h	Notes		
			50	100	150	200	250	300	350	400	450	500	510	520	530	540	550	560	570	580	590	600	620	640	650	660			680	700
Austenitic	BS 1504	304 C15A	160	143	127	115	109	104	101	99	95	92	91	90	88	81	75	68	62	57	52	47	38	31	27	23	18	100 000	7, 10	
													91	90	83	76	68	62	57	52	46	42	33	26	23	20	15	150 000		
													91	85	78	72	65	58	53	48	43	38	31	24	21	18	200 000			
													89	82	75	68	61	56	51	45	41	36	28	22	19	17	250 000			
Austenitic	BS 1504	316 C71	173	156	140	129	122	116	110	106	102	96					93	92	92	91	82	74	58	46	41	35	28	23	100 000	7, 10
																			92	85	75	66	52	41	36	32	25	19	150 000	
																			89	79	70	62	48	38	33	29	22	18	200 000	
																			85	75	66	58	45	35	31	27	22	18	250 000	
Austenitic	BS 1504	347 C17A	160	150	141	135	132	128	126	122	119	116																100 000	7, 10	
													114	113	113	109	99	91	82	74	66	53	41	35	31	22	150 000			
														113	112	102	93	84	75	68	61	48	37	32	28	22	200 000			
														113	106	98	88	79	72	64	58	45	34	29	25	19	250 000			

Table 3.2 Design stress values (continued)																					
(c) Steel forgings																					
Material	Forging standard	Steel grade	Ruling section mm	Values of f (N/mm ²) for design temperatures (°C) not exceeding																Design lifetime h	Notes
				50	100	150	200	250	300	350	390	400	410	420	430	440	450	460	470		
Carbon	BS 1503	164	≤ 100 150	203 187	187 173	171 159	156 145	142 137	128	121	116	115	114	105	90	77	65	56	48	42	
													111	95	81	68	58	50	43	38	
													104	88	75	63	54	46	40	34	
													98	83	70	59	51	43	37	32	
Carbon	BS 1503	221-410	≤ 100 > 100	143 137	134 126	125 116	121 113	112 108	100	95	92	92	92	92	90	77	65	56	48	42	
														92	81	68	58	50	43	38	
														88	75	63	54	46	40	34	
														83	70	59	51	43	37	32	
Carbon	BS 1503	221-430	≤ 100 > 100	150 143	141 133	133 124	129 121	119 115	107	102	99	99	99	98	90	77	65	55	48	42	
														99	95	81	68	58	50	43	
														99	88	75	63	54	46	40	
														98	83	70	59	51	43	37	
Carbon	BS 1503	221-460	≤ 100 > 100	163 157	154 146	145 135	140 131	129 125	117	112	109	108	108	105	90	77	65	56	48	42	
														108	95	81	68	58	50	43	
														104	88	75	63	54	46	40	
														98	83	70	59	51	43	37	
Carbon	BS 1503	221-490	≤ 100 > 100	177 170	167 158	157 146	151 141	140 135	128	122	119	118	118	105	90	77	65	56	48	42	
														118	105	90	81	68	58	50	
														118	104	88	75	63	54	46	
														115	98	83	70	59	51	43	
Carbon	BS 1503	221-510	≤ 100	190	177	165	159	147	135	129	125	124	124	121	105	90	77	65	56	48	
														124	111	95	81	68	58	50	
														121	104	88	75	63	54	46	
														115	98	83	70	59	51	43	
Carbon	BS 1503	223-410	≤ 100 > 100	163 153	150 141	138 129	130 121	120 115	106	99	93	92	92	91	90	77	65	56	48	42	
														91	81	68	58	50	43	38	
														88	75	63	54	46	40	34	
														83	70	59	51	43	37	32	
Carbon	BS 1503	223-430	≤ 100 > 100	173 163	160 149	148 134	139 129	128 123	114	107	101	100	99	98	90	77	65	56	48	42	
														99	95	81	68	58	50	43	
														99	88	75	63	54	46	40	
														98	83	70	59	51	43	37	

Table 3.2 Design stress values (continued)
(c) Steel forgings (continued)

Material	Forging standard	Steel grade	Ruling Section mm	Values of f (N/mm ²) for design temperatures (°C) not exceeding																	Design lifetime h	Notes
				50	100	150	200	250	300	350	390	400	410	420	430	440	450	460	470	480		
Carbon	BS 1503	223-460	≤ 100 > 100	193 180	179 166	164 153	151 141	140 135	127	119	113	111	110	105	90	77	65	56	48	42	8	
													110	95	81	68	58	50	43	38		
													104	88	75	63	54	46	40	34		
												98	83	70	59	51	43	37	32			
Carbon	BS 1503	223-490	≤ 100 > 100	209 197	194 182	179 167	165 153	152 146	139	131	125	123	121	105	90	77	65	56	48	42	8	
												123	111	95	81	68	58	50	43	38		
												121	104	88	75	63	54	46	40	34		
												115	98	83	70	59	51	43	37	32		
Carbon	BS 1503	223-510	≤ 100	217	203	190	173	159	147	138	132	131	121	105	90	77	65	56	48	42	8	
												128	111	95	81	68	58	50	43	38		
												121	104	88	75	63	54	46	40	34		
												115	98	83	70	59	51	43	37	32		
Carbon	BS 1503	224-410	≤ 100 > 100	157 147	146 137	136 127	125 117	114 109	101	94	90	89	88	88	88	77	65	56	48	42	8	
Carbon	BS 1503	224-430	≤ 100 > 100	167 157	156 146	145 135	133 123	121 117	108	101	97	96	95	95	90	77	65	56	48	42	8	
Carbon	BS 1503	224-460	≤ 100 > 100	183 170	170 158	157 147	145 135	132 127	118	111	106	105	105	104	90	77	65	56	48	42	8	
Carbon	BS 1503	224-490	≤ 100 > 100	203 187	187 173	171 159	156 145	142 137	128	121	116	115	115	105	90	77	65	56	48	42	8	
Carbon	BS 1503	224-510	≤ 100	210	194	179	163	149	135	128	124	122	121	105	90	77	65	56	48	42	8	
Carbon	BS 1503	225-490	≤ 100 > 100	209 200	199 187	189 173	172 163	160 154	147 145	137	131	130	121	105	90	77	65	56	48	42	8	

Table 3.2 Design stress values (continued)
(c) Steel forgings (continued)

Material	Forging standard	Steel grade	Ruling section mm	Values of f (N/mm ²) for design temperatures (°C) not exceeding																												Design lifetime h	Notes			
				50	100	150	200	250	300	350	400	410	420	430	440	450	460	470	480	490	500	510	520	530	540	550	560	570	580	590	600			610	620	
Alloy	BS 1503	620-440		183	166	149	142	131	123	113	108					105			101	101	93	76	62	52	42	33	27							8		
																			101	83	67	55	44	35	29	24										
																			94	76	61	49	40	32	26	22										
																			88	70	57	45	37	30	25	20										
Alloy	BS 1503	620-540	≤ 200	230	224	219	210	202	196	189	186					182	181	180	162	136	112	93	76	62	52	42	33	27							8	
																			181	174	149	124	102	83	67	55	44	35	29	24						
																			181	162	138	114	94	76	61	49	40	32	26	22						
																			179	155	131	107	88	70	57	45	37	30	25	20						
Alloy	BS 1503	621-460		183	173	163	156	145	137	127	122					117			115	114	112	93	76	62	52	42	33	27							8	
																			114	102	83	67	55	44	35	29	24									
																			114	94	76	61	49	40	32	26	22									
																			107	88	70	57	45	37	30	25	20									
Alloy	BS 1503	660-460		196	190	184	178	161	150	144	139					135			134	133	131	115	100	87	76	66	56								8	
																			133	122	106	92	80	69	59	47										
																			132	115	100	87	75	65	55											
																			128	111	96	83	72	62	50											
Alloy	BS 1503	271-560		238	229	220	215	208	204	199	192					188	186	181	155	129	107	87	69	54	41	30									2, 8	
																			173	145	118	95	76	60	44	32	23									
																			160	132	108	87	68	51	38	26	18									
																			157	129	105	83	65	48	35	23	14									
Alloy	BS 1503	622-490		183	176	169	163	157	153	149	145					137	135	132	131	118	105	94	82	72	61	53	45	39	34							2, 6, 8
																			132	122	108	97	85	73	63	56	48	42	36	31						
																			130	117	104	92	79	68	59	52	45	38	33	28						
																			126	113	100	87	75	65	57	49	42	36	32	27						
Alloy	BS 1503	622-560		238	231	224	219	213	209	201	197	196	195	194	183	170	157	143	131	118	105	94	82	72	61	53	45	39	34							2, 6, 8
																			195	186	173	161	148	135	122	108	97	85	73	63	56	48	42	36	31	
																			195	182	169	156	143	130	117	104	92	79	68	59	52	45	38	33	28	
																			190	178	165	152	139	126	113	100	87	75	65	57	49	42	36	32	27	
Alloy	BS 1503	762-690	≤ 250	294	276	259	249	240	233	227	219					206			190	187	173	155	138	122	107	93	80	68	58	48	40	33			8	
																			184	168	152	135	115	98	85	72	62	52	44	37	30					
																			180	164	146	128	110	94	80	68	58	49	41	34	28					
																			176	160	142	124	105	90	77	65	55	46	38	32	25					

Notes to table 3.2

General notes

- (a) Table 3.2 gives the nominal design stress (*f*) of various British Standard materials for design temperatures (°C) not exceeding those stated at the head of each column. Time-dependent values are given for lifetimes of 100 000, 150 000, 200 000 and 250 000 h are italicized. Values at intermediate temperatures and intermediate times shall be obtained by linear interpolation; values obtained by linear interpolation involving only one italicised value may be regarded as time-independent.
- (b) The design temperature as defined in section two should not exceed the upper temperature for which a value of (*f*) is given; where extrapolation of the values given is required, this shall be on a basis agreed between the purchaser and manufacturer (see 1.4.2.2(b)).
- (c) Overall thickness limits are as defined in the relevant material specification. In the case of forgings, the term 'ruling section' shall be interpreted in accordance with BS 5046.
- (d) For values between the thicknesses stated, design stresses shall be obtained by linear interpolation.

Notes applicable to individual materials

1. The use of this material shall be limited to pressures not exceeding 21 bar.
2. At temperatures at or above 580 °C the effect of scaling becomes significant and due allowance shall be made for this.
3. Text deleted.

4. Design stress values are not strictly based on specified yield/proof stress values in the relevant material standard (see appendix B).
5. Text deleted.
6. The time-dependent values are lower than those established by experience and established values up to 10 % higher may be permitted subject to fitness-for-continued-service reviews being instituted at two-thirds of the design lifetime (see 2.8) and by agreement between the purchaser and the manufacturer (see 1.4.2.2(c)) providing the resulting value does not exceed the lowest time-independent stress value given.
7. An appropriate casting quality factor as specified in 4.5 should be applied to these values.
8. Material will (or may) be supplied in the quenched and tempered condition, in which case time-dependent properties may be susceptible to degradation as a result of subsequent fabrication processes.
9. For grade 591 it has not yet been possible to establish confidence limits, therefore an elevated temperature proof test shall be carried out. Values above 400 °C are not included due to absence of data.
10. Time-dependent design stress values apply only if the minimum carbon content equals or exceeds 0.04 %.

Section four. Design

4.1 General

The pipes and piping installations shall be designed in accordance with 4.2 to 4.13 to withstand the design pressure (see section two) at the design temperature (see section two) sustained, where relevant, for the design lifetime (see 2.8).

NOTE 1. This section also covers the assessment of stresses arising from the thermal expansion and deadweight loading of piping systems.

NOTE 2. Pipework designed in accordance with this section is suitable for 10^4 cycles at full pressure (zero to design pressure) and/or full temperature (ambient to design temperature).

4.2 Thickness of wrought steel straight pipes

The minimum thickness t_f (in mm) of straight pipes shall be calculated in accordance with either (a) or (b):

(a) using the outside diameter as the basis for calculation:

$$t_f = \frac{pD}{2fe + p} \quad (4)$$

(b) using the inside diameter as the basis for calculation:

$$t_f = \frac{pd}{2fe - p} \quad (5)$$

For (a) and (b) above

p is the design pressure (in N/mm^2);

D is the mean outside diameter (in mm);

d is the mean inside diameter (in mm);

f is the maximum permissible design stress (in N/mm^2) for the material in accordance with 3.2;

e is a factor, having the following values:

$e = 1.0$ for seamless and for electric resistance welded and induction welded pipes complying with BS 3601, BS 3602 : Part 1, BS 3604 : Part 1 and BS 3605 : Part 1;

$e = 1.0$ for longitudinally arc welded pipes complying with BS 3602 : Part 2 and BS 3604 : Part 2;

$e = 0.9$ for submerged arc welded pipes complying with BS 3601.

NOTE 1. The value of t_f determined from equations (4) and (5) is the minimum thickness of straight tubes and further provision will be needed for minus thickness tolerances, where necessary.

NOTE 2. Designers' attention is drawn to 5.3.3.1(c).

4.3 Wrought steel bent pipes

NOTE. Pipe bends may be made by various forming processes or by welding together halves pressed from plate. The design thickness requirements specified in this clause apply to all processes.

4.3.1 Thickness of bends

Bends shall have a minimum wall thickness not less than t_f except in the cases of 4.3.2.1(b) and (c). The minimum thickness t_b of a straight pipe from which a pipe bent to a radius in accordance with table 4.3.1 is to be made shall be determined from equations (6) or (7), except where it can be demonstrated that the use of a thickness less than t_b would not reduce the thickness below t_f at any point after bending.

For pipes 219.1 mm outside diameter and below, and for pipes above 219.1 mm outside diameter bent to the radii given in column 2 of table 4.3.1, t_b shall be given by:

$$t_b = 1.125t_f \quad (6)$$

For pipes above 219.1 mm outside diameter, where t_f is 32 mm or more, bent to the radii given in column 3 of table 4.3.1, t_b shall be given by:

$$t_b = 1.1t_f \quad (7)$$

The value of t_b is the minimum thickness and provision shall be made for minus tolerances.

NOTE. Manufacturing considerations may make it necessary for pipes thicker than this minimum to be used.

4.3.2 Radii of bends

4.3.2.1 Pipes complying with BS 1387 and BS 3601 shall not be bent to radii less than those given in table 4.3.1.

Other pipes of a thickness determined as in 4.3.1 shall not be bent to radii less than those given in table 4.3.1 unless:

(a) it can be demonstrated that the use of this thickness will not reduce the thickness at any point after bending to below t_f ; and

(b) where the design stress is time-dependent and the bend radius is less than 3 times the inside diameter, the intrados thickness t_i (in mm) shall not be less than that calculated from the following:

$$t_i = t_f \times \frac{2R - r}{2R - 2r}; \text{ or} \quad (8)$$

(c) where the design stress is time-independent and the bend radius is less than 1.5 times the inside diameter, the intrados thickness t_i (in mm) shall not be less than that calculated from the following:

$$t_i = \frac{t_f}{1.25} \times \frac{2R - r}{2R - 2r} \quad (9)$$

For (b) and (c) above

R is the radius of the bend (in mm);

r is the mean radius of the pipe (in mm).

4.3.2.2 There is a minimum thickness for each size of pipe, dependent on bending procedure, below which the allowance for thinning will be exceeded, and in such cases the radius given in table 4.3.1 shall be increased, where necessary, to ensure that the thickness is not below t_f at any point after bending.

4.3.2.3 Minimum radii of bends of carbon manganese niobium and alloy steel pipes which are cold bent without subsequent heat treatment, shall comply with 5.2.2.

4.3.2.4 For pipes rolled to a specified inside diameter, the minimum bending radii and corresponding thinning allowance shall be that applicable to the nearest outside diameter listed in table 4.3.1 greater than that resulting from the specified inside diameter plus $2t_b$.

Table 4.3.1 Minimum bending radii for wrought steel bent pipes		
Outside diameter	Radii measured to centre line of pipe	
	$t_b = 1.125 t_f$ for all thicknesses	$t_b = 1.1 t_f$ where $t_f = 32$ mm or above
mm	mm	mm
26.9	65	
33.7	75	
42.4	100	
48.3	115	
60.3	150	
76.1	190	
88.9	230	
101.6	265	
114.3	305	
139.7	380	
168.3	460	
193.7	630	
219.1	710	
244.5	810	1140
273.0	1020	1270
323.9	1220	1520
355.6	1500	1780
406.4	1730	2030
457.0	2030	2280

4.4 Gusseted bends

4.4.1 General

There are two types of gusseted bends: mitred (segmental) bends which shall comply with 4.4.2 and cut-and-shut bends, which shall comply with 4.4.3.

4.4.2 Design of gusseted bends: mitred (segmental)

4.4.2.1 Mitred bends shall not be used at a design temperature above 400 °C.

4.4.2.2 Mitred bends shall be fabricated from separate pieces of pipe cut in a plane other than perpendicular to the pipe axis and welded together. Mitred joints shall be made only by cutting the faces of adjacent segments at the same angle which shall not exceed 15°, as shown in figure 4.4.2.2.

4.4.2.3 The ratio of the inside diameter to the mean thickness of the bend shall be not less than 20 nor more than 200.

4.4.2.4 The minimum thickness t_g (in mm) of the pipe wall at a mitred bend shall be not less than the following.

Where the outside diameter is the basis for the calculation:

$$t_g = \frac{D}{2X + 1} \quad (10)$$

Where the inside diameter is the basis for the calculation:

$$t_g = \frac{d}{2X - 1} \quad (11)$$

where

D is the mean outside diameter (in mm);

d is the mean inside diameter (in mm);

X is found from figure 4.4.2.4 with e , f and p as defined in 4.2.

The value of t_g is the minimum thickness for mitred bends, and provision shall be made for any minus tolerance.

NOTE. Manufacturing considerations may make it necessary for pipes thicker than this minimum to be used.

4.4.2.5 The distance between mitred joints measured along the centre line of the pipe shall be not less than L_m (in mm) (see figure 4.4.2.2):

$$L_m = Cr \quad (12)$$

where

r is the mean radius of the pipe, based on mean thickness (in mm);

$$C = \frac{1.833}{\sqrt{r/t}} + 2 \tan \alpha; \quad (13)$$

α is as shown in figure 4.4.2.2;

t is the mean thickness of the pipe (in mm).

NOTE. It may be necessary to increase the distance between mitred joints to a figure greater than L_m either from constructional considerations or to satisfy the requirements for attachment of branches or brackets.

4.4.2.6 The minimum thickness, t_g , shall be maintained for a distance of at least L_m on either side of the joint measured axially along the centre line of the pipe (see figure 4.4.2.2).

4.4.2.7 It is permissible to weld attachments to bends designed in accordance with 4.4.2.5 for supporting and other purposes. If attachments are made across one or more mitred joints, the distance measured from the edge of an attachment to the centre line of the next mitred joint shall be at least $1.833 \sqrt{rt}$ (see figure 4.4.2.2). Where attachments are made across mitred joints, flexibility factors require special consideration.

4.4.3 Cut-and-shut bends

Cut-and-shut bends shall not be used for design pressure or temperature conditions exceeding 21 bar or 260 °C.

4.5 Thickness of cast steel straight pipes and bends

The use of cast steel pipes and bends shall be restricted to inspection categories I, II and V of BS 1504.

Cast steel straight pipes and bends shall be used only by agreement between the purchaser and the manufacturer (see 1.4.2.3(c)). Where such pipes and bends are used, the areas to be inspected and the inspection techniques to be adopted shall also be agreed between the purchaser and the manufacturer (see 1.4.2.3(c)).

Where cast steel straight pipes and bends are to be butt welded to wrought pipes, the butt weld ends shall be included in the areas of inspection and, if the casting is manufactured from 2¼ % Cr or CrMoV steels, the suitability for ultrasonic examination shall be confirmed by attenuation checks in accordance with 9.3 of BS 6208 : 1982.

The minimum thickness t_f (in mm) of cast steel straight pipes and bends, determined from equation (14), shall not be less than 9.5 mm:

$$t_f = \frac{pd}{2fF - p} \quad (14)$$

where

- p is the design pressure (in N/mm²);
- d is the inside diameter of the pipe (in mm);
- f is the maximum permissible design stress (in N/mm²) for the material (see 3.2);
- F is the casting quality factor, the value of which is dependent on the inspection category as follows:
 - (a) 1.0 for plain cylindrical areas local to butt weld ends up to a maximum distance of $2.5t$, where t is the mean thickness of the pipe (in mm) from the butt weld and where the whole of this area is inspected to a standard not less than severity level I of ASTM E186, E280 or E446* whichever is applicable;
 - (b) 0.9 for castings inspected to category I of BS 1504 except butt weld ends as specified in (a);
 - (c) 0.8 for castings inspected to category II of BS 1504 except butt weld ends as specified in (a);
 - (d) 0.7 for castings inspected to category V of BS 1504, except butt weld ends as specified in (a).

* ASTM E186 'Standard reference radiographs for heavy-walled (2 to 4½ in. (51 to 114 mm)) steel castings'

ASTM E280 'Standard reference radiographs for heavy-walled (4½ to 12 in. (114 to 305 mm)) steel castings'

ASTM E446 'Standard reference radiographs for steel castings up to 2 in. (51 mm) in thickness'

The ASTM standards are published by the American Society for Testing and Materials (ASTM) and copies of the radiographs may be examined at the offices of the Steel Castings Research and Trade Association (SCRATA) at the following address, by prior appointment only, at no charge: 5 East Bank Road, Sheffield S2 3PT.

4.6 Thickness of cast iron pipes and fittings

Cast iron pipes shall not be used for steam or blowdown duties under any conditions.

Grey iron pipes and fittings shall not be used when the design temperature exceeds 220 °C.

Ductile iron pipes and fittings shall not be used when the design temperature exceeds 350 °C.

The minimum thickness for grey iron pipes and fittings when used for duties other than steam or blowdown shall be in accordance with BS 4622 for the applicable conditions.

The minimum thickness for ductile iron pipes and fittings when used for duties other than steam or blowdown shall be in accordance with BS 4772 for the applicable conditions.

4.7 Joints

4.7.1. The flanges and bolting for ordinary bolted flange joints shall comply with BS 4504 : Section 3.1 or BS 1560 : Section 3.1 for flanges which are dimensioned in millimetres or with BS 10 for flanges which are dimensioned in inches. Gasket selection (material, thickness, etc.) shall be such that the gasket factor and seating stress are consistent with the flanges and bolting.

NOTE. Special joints and special types of flange may be used provided that they are shown to be suitable for the design conditions.

4.7.2 Butt welded joints shall comply with 5.3.

4.7.3 It is permissible to use socket weld joints with carbon and low alloy steel pipes not exceeding 60.3 mm outside diameter, but such joints shall not be used where fatigue, severe erosion or crevice corrosion is expected to occur.

The thickness of socket weld fittings shall be in accordance with 4.2, but shall be not less than 1.25 times the nominal thickness of pipe or tube. The throat dimension of the fillet weld shall be not less than the nominal thickness of the pipe or tube. The material shall be compatible with the associated piping.

Socket weld fittings shall be of forged steel. The dimensions and clearances of the socket end shall comply with BS 3799.

The welding of socket weld joints shall be in accordance with BS 2633, BS 2971 or BS 4677, as appropriate.

4.7.4 Screwed joints shall not be used in service where severe erosion, crevice corrosion, shock or fatigue is expected to occur.

Where screwed joints are used they shall comply with the following.

(a) Screwed joints between pipes complying with BS 1387 and fittings complying with BS 1740 are permitted at temperatures not exceeding 260 °C and within the pressure limits given in table 4.7.4(1).

(b) Screwed joints with fittings complying with BS 143 & 1256 are permitted at temperatures not exceeding 260 °C and within the pressure limits given in table 4.7.4(1) but subject to further limitation given in BS 143 & 1256.

(c) Screwed joints are permitted at temperatures exceeding 260 °C and size/pressure limits in excess of those given in table 4.7.4(1) providing the following conditions are satisfied:

(1) all threads are tapered unless pressure tightness depends on a seal weld or a seating surface other than the threads and experience or test demonstrates the suitability of the joint;

(2) pressure/temperature ratings in appropriate component standards, e.g. BS 3799, are not exceeded;

(3) the minimum specified tensile strength of screwed pipe is greater than 330 N/mm²;

(4) the thickness of screwed pipe is not to be less than that given in table 4.7.4(2);

(5) the design temperature does not exceed 495 °C;

(6) the pressure limits given in table 4.7.4(3) are not exceeded.

(d) Screwed joints are permitted for temperatures in excess of 495 °C and pressures in excess of those given in table 4.7.4(3) for instrument insertions and tappings and for plugs for access openings for radiographic inspection providing the following conditions are satisfied:

(1) they do not exceed 50 mm nominal size or one-quarter of nominal pipe size, whichever is the smaller;

(2) the minimum thread engagement is not less than:
6 for up to and including 20 mm nominal bore;
7 for over 20 mm up to and including 40 mm nominal bore;
8 for over 40 mm up to and including 50 mm nominal bore;

(3) the connection is seal welded;

(4) the design of instrument insertion withstands the fluid characteristics, fluid flow and any vibrations.

(e) Screwed joints are permitted for pressures in excess of those given in table 4.7.4(3) up to 345 bar for dead end instrument lines at the outlet end and downstream of shut-off valves and instruments, control apparatus or discharge of a sample cooler providing that the nominal size of pipe does not exceed 12 mm.

4.7.5 Sleeve welded joints shall not be used.

Table 4.7.4(1) Maximum permissible pressures for screwed joints using pipe complying with BS 1387 and fittings complying with BS 1740

Nominal pipe size	Maximum pressure for temperatures not exceeding 260 °C	Joint type
mm	bar	
6	10.5	Taper/parallel
8	10.5	Taper/parallel
10	10.5	Taper/parallel
15	10.5	Taper/parallel
20	10.5	Taper/parallel
25	10.5	Taper/parallel
32	9.0	Taper/parallel
40	9.0	Taper/parallel
50	12.5	Taper/taper
65	12.5	Taper/taper
80	10.5	Taper/taper
100	9.0	Taper/taper

NOTE. The efficiency of the taper/parallel screwed joints is highly dependent on the degree of care taken in assembly and on the jointing compound used.

Taper/taper screwed joints are less sensitive to jointing techniques and external forces.

This table excludes screwed-on flanges (see 5.5.3).

Table 4.7.4(2) Minimum thickness of screwed pipe complying with 4.7.4(c)

Nominal pipe size	Minimum thickness	
	17.5 bar and less for steam 7 bar and less for water over 105 °C	Over 17.5 bar for steam Over 7 bar for water over 105 °C
mm	mm	mm
8	2.24	3.02
10	2.31	3.20
15	2.77	3.75
20	2.87	3.91
25	3.38	4.55
32	3.56	4.85
40	3.68	5.08
50	3.91	5.54
65	5.16	7.01
80	5.49	7.62

Table 4.7.4(3) Maximum pressure for screwed pipe complying with 4.7.4(c)

Nominal pipe size	Maximum pressure
mm	bar
Over 50 up to and including 80	27.5
Over 25 up to and including 50	41.5
Over 20 up to and including 25	83
Up to and including 20	103.5

4.8 Branches

4.8.1 General

Branches shall not be welded to any main at an included angle less than 60°.

4.8.2 Branch connections to mitred gusseted bends

Branch connections shall be made to segments only if their inside diameters do not exceed 10 % of the diameter of the main. Branches shall be designed in accordance with 4.8.3 and 4.8.4. The distance measured from the intersection of the bore of the branch with that of the main to the centre line of the nearest mitred joint shall be not less than the greater of:

$$1.833 \sqrt{(d_1 + t_1) \times t_1/2} \quad \text{or} \quad 1.833 \sqrt{(D_1 - t_1) \times t_1/2}$$

or

$$\frac{d_2}{\sin \gamma}$$

where

t_1 is the mean thickness of the main (in mm);

D_1 is the mean outside diameter of the main (in mm);

d_1 is the mean inside diameter of the main (in mm);

d_2 is the mean inside diameter of the branch (in mm);

γ is the angle between the branch and the main (in degrees).

NOTE. The dimensional parameters are illustrated in figure 4.8.2.

4.8.3 Reinforcement and branch thickness

Whenever possible, the form of the reinforcement provided shall be by either (a) or (b):

(a) when the thickness of the main is not predetermined, by providing main and branch in accordance with 4.8.5; or

(b) when the thickness of the main is predetermined, by providing a branch in accordance with 4.8.6.

When reinforcement in accordance with either (a) or (b) cannot be provided, other means of reinforcement, the use of which has been substantiated by adequate relevant service experience or by experimental or theoretical analysis, shall be agreed between the purchaser and the manufacturer (see 1.4.2.3(d)).

When branch connections are reinforced in accordance with (a) or (b), the ratio of branch thickness to main thickness shall comply with the following limitation:

$$\frac{t_2}{t_1} \leq \left(2 - \frac{D_2}{D_1}\right)$$

where

D_1 is the mean outside diameter of the main (in mm);

D_2 is the mean outside diameter of the branch (in mm);

t_1 is the mean thickness of the main (in mm);

t_2 is the mean thickness of the branch (in mm);

In no case shall the thickness of the main or branch be less than t_r , determined in accordance with 4.2.

It is preferable for main and branch to be of the same material, but in no case shall branch material have an allowable stress of less than 75 % of that of the material of the main. No credit shall be taken where the branch material has an allowable stress that is greater than that of the main.

The minimum branch thickness t_{m2} , determined from equation (20), assumes the same material for branch and main. If the branch is of a material having a lower allowable stress than the main, then the branch thickness shall be increased in the ratio of allowable stress.

Branches designed in accordance with 4.8.5 or 4.8.6 shall be 'set on' full penetration welded, or non-protruding 'set in' full penetration welded, or shall be of homogeneous construction.

4.8.4 Branch systems

In assessing main and branch thickness in accordance with 4.8.5 and 4.8.6, it shall be determined whether branches affect each other by calculation of:

$$\frac{L}{d_{2m} + d_{2n}} \quad (15)$$

where

L is the distance between perpendiculars projected from the openings of adjacent branches to the centre line of the main (in mm) (see figure 4.8.4);

d_{2m} and d_{2n} are the mean inside diameters of the branches under consideration (in mm). The subscripts m and n represent the branch suffixes a, b and c, etc (see figure 4.8.4).

Branches shall be deemed to affect each other if the value calculated from expression (15) is less than one; they shall be deemed not to affect each other if the value is greater than or equal to one.

In calculating the thickness required, each branch shall be considered in turn together with all the branches by which it is affected (see figure 4.8.4 for typical examples).

4.8.5 Reinforcement in accordance with 4.8.3(a) (proportional thickening of main and branch)

4.8.5.1 Branch not affected by any other branch. The minimum thicknesses of the branch t_{m2} (in mm) and the main t_{m1} (in mm) shall be determined from equations (16) and (18) or (17) and (19).

$$t_{m2} = \frac{pD_{2\gamma}}{2f_2e_2x + p} \quad (16)$$

or

$$t_{m2} = \frac{pd_{2\gamma}}{2f_2e_2x - p} \quad (17)$$

$$t_{m1} = \frac{pD_1}{2f_1e_1x + p} \quad (18)$$

or

$$t_{m1} = \frac{pd_1}{2f_1e_1x - p} \quad (19)$$

where

- p is the design pressure (in N/mm²);
 D_1 is the mean outside diameter of the main (in mm);
 D_2 is the mean outside diameter of the branch (in mm);
 $D_{2\gamma} = D_2/\sin \gamma$
 d_1 is the mean inside diameter of the main (in mm);
 d_2 is the mean inside diameter of the branch (in mm);
 $d_{2\gamma} = d_2/\sin \gamma$
 f_1 is the allowable design stress of the main (in N/mm²) (see 3.2);
 f_2 is the allowable design stress of the branch (in N/mm²) (see 3.2) but not greater than f_1 ;
 e_1 is the factor given in 4.2 particular to the main;
 e_2 is the factor given in 4.2 particular to the branch;
 x is the factor from figure 4.8.5.1 read against $d_{2\gamma}/d_1$. Where $d_{2\gamma}/d_1$ does not exceed 0.3; the x value derived from figure 4.8.5.1 shall be used only to determine main thickness, and the branch thickness shall be determined by using an x factor of 1.0.

NOTE 1. The minimum branch thicknesses as calculated are a function of the branch inside or outside diameter used in the calculation according to the equation used. If practical availability considerations require that the branch inside or outside diameter be increased above the value used in the calculation, then t_{m2} has to be recalculated.

NOTE 2. The values of t_{m1} and t_{m2} are minimum thicknesses and further provision has to be made for minus tolerance.

4.8.5.2 A branch affected by one or more other branches.
The thickness of the main shall be determined from equation (18) or (19) using the x factor applicable to the largest $d_{2\gamma}$ of the group.

NOTE. Where $d_{2\gamma}/d_1$ ratio exceeds 0.8, in order to limit iteration it is suggested that the main thickness obtained from equation (18) or (19) be multiplied by the factor 1.25 $d_{2\gamma}/d_1$.

The thickness of each branch shall be obtained from equation (20), except that where $d_{2\gamma}/d_1 \leq 0.3$ and the mean diameter of the branch ($d_2 + t_f$) complies with the limitation of inequality (23), the branch minimum thickness t_{m2} shall be t_f obtained from equation (4) or (5) of 4.2:

$$t_{m2} = \frac{K}{2 - K} d_{2\gamma} \quad (20)$$

where

$$K = \sqrt{\frac{\varepsilon}{Zn}} \quad (21)$$

$$\text{in which } \varepsilon = \frac{2t_a}{d_1 + t_a} \text{ or } \frac{2t_a}{D_1 - t_a} \quad (22)$$

$$d_2 + t_f \leq h \delta \quad (23)$$

$$\text{in which } \delta = \sqrt{2t_a(d_1 + t_a)} \text{ or } \sqrt{2t_a(D_1 - t_a)} \quad (24)$$

Z is read from curve figure 4.8.5.2(1) by entering at x_a and reading from the appropriate $d_{2\gamma}/d_1$ line;

x_a is as defined in equation (27);

$n = g_1 g_2 g_3$ for each group of branches considered (see equation (25));

t_a is the actual minimum thickness of main at junction with branch, i.e. minimum measured thickness where pipe is available, or ordered thickness less tube maker's tolerance (in mm);

h is read from curve figure 4.8.5.2(2) by entering at Zn ;

$$g_1 = 1 - C_1(1 - Y)$$

$$g_2 = 1 - C_2(1 - Y)$$

$$g_3 = 1 - C_3(1 - Y)$$

(25)

$$Y = \frac{p(d_1 + t_a)}{2f_1 e_1 t_a} \quad (26)$$

where d_1 , f_1 and e_1 are in accordance with 4.8.5.1;

C_1 , C_2 , C_3 are functions of the distances between the branch being considered and the branch or branches affecting that branch. The C value is obtained from table 4.8.5.2;

L is the distance between projections of branch inside diameters, d_{2m} and d_{2n} , where the subscripts m and n represent the branch designations under consideration (see figures 4.8.4(b) to 4.8.4(d));

$$x_a = \frac{J}{Y} \quad (27)$$

$J = 2.2$ except where $d_{2\gamma}/d_1 \leq 0.3$, when $J = 2.5$;

Y is as calculated from equation (26).

Where x_a is less than 2.5, the main thickness, t_a , is inadequate and shall be increased.

Table 4.8.5.2 Factor C

$\frac{L}{d_{2m} + d_{2n}}$	C
1 or greater	0
0.9	0.10
0.8	0.34
0.7	0.66
0.6	0.80
0.5	0.90
0.4	0.94
0.3	0.97
0.2	0.98
0.1	0.99
0	1

NOTE. Intermediate values may be obtained by linear interpolation.

4.8.6 Reinforcement in accordance with 4.8.3(b)
(branch reinforcement when the thickness of the main is predetermined)

4.8.6.1 Branch not affected by any other branch. The branch thickness shall be determined from equation (20) or inequality (23) (see 4.8.5.2) in conjunction with equation (27), using a value of $n = 1$ for these equations.

4.8.6.2 Branch affected by one or more other branches. All branch thicknesses shall be determined from equation (20) or inequality (23) in conjunction with equations (25), (26) and (27).

4.8.7 Length of branch reinforcement

The additional thickness of the branch determined from equations (16), (17) and (20) for reinforcement shall extend for a distance not less than $\sqrt{D_2 t_{m2}}$ measured from the outside diameter of the main along the centre line of the branch (see figure 4.8.4(a)).

4.8.8 Mains (see figure 4.8.4)

The additional thickness of a main for branch reinforcement shall, in the case of a branch not affected by any other branch, extend on each side of the branch for a distance that is not less than d_{2y} . The distance shall be measured from the periphery of the branch inside diameter.

Where the branch is affected by one or more other branches, the main reinforcement distance shall be as shown in figure 4.8.4.

NOTE. Appendix C gives worked examples of reinforcement.

4.9 Safety valve discharge piping and safety valve mounting

4.9.1 The safety valve discharge piping shall comply with 2.7.

NOTE. For guidance on safety valve mounting, see appendix B of BS 6759 : Part 1 : 1984.

Discharge piping shall have a bore not less than the bore of the outlet connection of the safety valve. The discharge pipes shall be as short and straight as possible. Each discharge system shall have an individual and unrestricted drain for every part of the system. The drain shall be laid with a continuous fall to a place where the discharge cannot injure any person.

Discharge pipes shall be so arranged that no excessive loads are imposed on the safety valve under any conditions. Where an expansion chamber is used, this shall be properly anchored and shall make allowance for the hot and cold positions of the safety valve outlet branch. It shall be so positioned that in the hot position the safety valve outlet branch is concentric with the expansion chamber. Where an expansion slip joint only is used, this shall be properly restrained against upward thrust.

The design shall ensure that the discharge pipe immediately downstream of the valve, but upstream of

the slip joint, if one is fitted, is as short as possible, and complies with any requirements for dimensions that the valve manufacturer may advance.

If the details of the discharge pipe are not specified by the valve manufacturer, the design of this pipe shall be carried out in liaison with the valve manufacturer in order that the valve performance will not be affected in any way by the design of the discharge pipe.

4.9.2 Discharge piping incorporating an expansion chamber or slip joint shall be of an adequate diameter so that the operating pressure applying immediately on the discharge side of the expansion chamber or slip joint will not cause steam to blow back in the immediate vicinity of the fittings.

4.9.3 Where flexible bellows are used, they shall comply with the following.

- (a) An internal liner or sleeve shall be fitted and attached to the body of the bellows fittings, at the inlet end, with a continuous strength weld. The contour internally shall be as smooth as possible and the bore of the internal liner or sleeve shall not be less than that of the adjacent inlet piping.
- (b) The bellows shall be designed to contain end thrust unless the adjacent piping is adequately anchored to cater for such thrust.
- (c) The annulus between the internal sleeve and the bellows shall be drained.
- (d) The design of the bellows shall be such as to withstand vacuum conditions which may be created in the annulus.

NOTE. See also BS 6129 : Part 1.

4.10 Expansion allowance

The allowance for expansion in millimetres per metre of piping at various temperature ranges shall be as given in table 4.10.

NOTE. For coefficients of linear expansion see appendix D.

4.11 Flexibility

4.11.1 General

Maximum values for the forces and moments that may be applied to the connected equipment shall be agreed between the purchaser and the manufacturer (see 1.4.2.2(d)).

Anchors shall be designed to ensure that there is no slipping or twisting of the pipes.

Where terminal forces and moments are of a critical nature (see 1.4.2.2(d)), a balanced erection procedure for the pipework shall be considered (see 5.10).

The pipes shall be arranged so that the system is sufficiently flexible to ensure that the end reactions, under any operating conditions either hot or cold within the

Table 4.10 Expansion allowance				
Temperature	Expansion			
	Carbon and low alloy steel	BS 3604 steel 762	Austenitic stainless steels	Cast iron
°C	mm/m	mm/m	mm/m	mm/m
20 to 50	0.36	0.33	0.49	0.29
20 to 100	0.98	0.88	1.34	0.78
20 to 150	1.62	1.45	2.20	1.27
20 to 200	2.30	2.04	3.08	1.76
20 to 250	3.00	2.64	3.99	
20 to 300	3.73	3.25	4.92	
20 to 350	4.49	3.88	5.86	
20 to 400	5.27	4.53	6.83	
20 to 450	6.08	5.19	7.82	
20 to 500	6.92	5.86	8.83	
20 to 550	7.79	6.55	9.86	
20 to 600	8.68	7.26	10.91	
20 to 650			11.99	
20 to 700			13.08	
20 to 750			14.19	

limits of the design temperature and pressure, do not exceed these maximum values. The pipes shall also be arranged so that the system is sufficiently flexible to absorb the whole of its own expansion and that of the connecting equipment without exceeding the requirements specified in 4.11.2. Where practicable, the requisite flexibility shall be provided in the layout of the pipes.

Where lack of space or other considerations prohibit the use of this method, the use of expansion fittings shall be permitted, provided that the limitations imposed by maximum design pressure, drainage, etc. are taken into account.

If expansion fittings are used, detailed consideration shall be given to the design of anchors, guides and ties to ensure that these protect the expansion fitting and accommodate the additional loads due to pressure including any applied test pressure. (See also BS 6129 : Part 1.)

A flexibility analysis shall be carried out if there is any doubt as to the ability of the system to satisfy the specified requirements.

In calculating the flexibility of a piping system, the following requirements shall be observed.

- Wherever possible, piping systems shall be treated as a whole between anchor points.
- Where it is necessary to make simplifying assumptions for the purpose of reducing the complexity of the flexibility analysis, particulars of such simplifications shall be recorded.
- All linear and rotational restraints shall be taken into account.

(d) Linear and rotational behaviour of connecting equipment shall be taken into account.

(e) Flexibility and stress intensification factors for bends and branches shall be utilized (see figures 4.11.1(1) to 4.11.1(8)). The flexibility factor for single mitred bends shall be taken as unity. A flange correction factor of bend stress intensification and flexibility shall be used where applicable (see figure 4.11.1(9)). In no case shall the product of the stress intensification factor and the flange correction factor be taken as less than unity.

(f) The thermal expansion shall be determined from table 4.10 or appendix D.

(g) The modulus of elasticity shall be determined from table 4.11.1.

(h) Pipe effects on connecting equipment due to thermal behaviour of the system shall have a sign convention to indicate the forces and moments imposed on the equipment.

The purchaser shall be advised on the basis of the calculations, e.g. whether deadweight has been taken into account, whether they are based on expansion and cold pull only, and also what allowances have been included to cover for practical variations on applied cold pull, for tolerances on pipe dimensions, pipe supports, etc., configuration and other relevant factors.

(i) The pipe dimensions used in flexibility calculations shall be the mean thickness, t , and mean outside diameter, D (or mean inside diameter, d) as defined in 1.3.2.

Table 4.11.1 Typical values of modulus of elasticity				
Temperature	Modulus of elasticity			
	Carbon steels 320, 360, 430, 490, 500 Nb	Alloy steels 591, 620, 621, 622, 660	Alloy steel 762	Austenitic stainless steels
°C	N/mm ²	N/mm ²	N/mm ²	N/mm ²
20	210 000	210 000	215 000	205 000
100	205 000	205 000	210 000	195 000
200	200 000	200 000	205 000	190 000
300	190 000	195 000	195 000	180 000
400	185 000	185 000	190 000	170 000
500	(175 000)	175 000	180 000	160 000
600	(165 000)	165 000	165 000	155 000
700	—	—	—	145 000
800	—	—	—	135 000

NOTE 1. Intermediate values may be obtained by interpolation.
NOTE 2. The values in parentheses are indicative.

It is permissible to pre-stress the pipes to reduce end effects under hot conditions of working and also to reduce hot stress levels.

When the design temperature is such that the permissible hot stress is to be limited by the creep rupture properties as defined under 4.11.2(b), the amount of cold pull should preferably be 100 % but shall not be less than 85 % of the total calculated expansion of the system, except where sections of one system between anchors are simultaneously subject to different temperatures.

4.11.2 Maximum permitted stress range, hot stress and sustained stress

At no point in the pipes under cold or any operating condition within the design limits shall any one of the following criteria be exceeded.

- (a) *Maximum stress range.* The maximum stress range shall be the lower of:
- (1) H times the proof stress at room temperature plus H times the proof stress at design temperature; or
 - (2) H times the proof stress at room temperature plus average stress to rupture in the design life at the design temperature;

where

$H = 0.9$ for all cases except at branch junctions where $d_2/d_1 \leq 0.3$, when $H = 1.0$.

(b) *Maximum hot stress.* Where (a) (2) is the criterion of stress range, the maximum hot stress determined in accordance with 4.11.3.1(b) shall not exceed the average stress to rupture in the design life at the design temperature.

(c) *Sustained combined stress.* Except at branch junctions, the sustained combined stress shall not exceed the lower of 0.8 times the proof stress value or the creep rupture design stress value given in table 3.2 under cold or any other operating condition.

At branch junctions designed in accordance with 4.8, i.e. on the basis of shakedown, the non-intensified dead load stress shall not exceed 15 % of the component design stress value given in table 3.2.

Where a hydraulic test is to be applied to a completed system in accordance with 6.2, then the sustained stress due to hydraulic test pressure, pipe weight and water weight shall not exceed 0.9 times the proof stress at test temperature.

NOTE. Recommended proof and average creep rupture stress values are given in appendix E. For steels not covered by appendix E, reference should be made to the applicable materials standards.

In calculating the stress levels the following loadings shall be included as shown in table 4.11.2:

- (i) pressure;
- (ii) thermal (see 4.11.1);
- (iii) deadweight including sustained external loads;
- (iv) cold pull.

Table 4.11.2 Allocation of loads			
Loading	Stress range	Hot stress	Sustained stress
Pressure	X	X	X
Thermal	X	X	–
Deadweight	–	X	X
Cold pull	–	X	–

4.11.3 Calculation of stress levels*

4.11.3.1 In calculating stress levels the following shall apply.

(a) In calculating the combined stress to satisfy the stress range limitation (see 4.11.2(a)).

(1) The complete expansion between cold and hot shall be considered in evaluating the bending stress which should be based on the modulus of elasticity for the cold condition.

(2) Where a pipework system can be sectionalized so that any point can be subject to conditions other than all hot or all cold, then in addition to the stress range calculation of (1), the maximum stress range based on the maximum difference between bending moments in each plane at that point, when combined with the highest pressure stress associated with these moments, shall not exceed the sum of 0.9 times the proof stress at the temperature at each end of the applicable cycle.

The modulus of elasticity for the lowest temperature applicable to this condition shall be used.

(b) In calculating the combined stress to satisfy the hot stress limitation (see 4.11.2(b)).

(1) The expansion between cold and hot minus the theoretical cold pull shall be used in evaluating the bending stress. The modulus of elasticity for the hot conditions shall be used.

(2) Where a pipework system can be sectionalized so that any point can be subject to conditions other than all hot or all cold, then the higher value of either the maximum moment or the maximum difference between the maximum moment and 0.5 times the minimum moment in any plane under each hot condition of operation shall be considered in addition to the cold-to-hot definition as given in (1). The modulus of elasticity for the hot condition shall be used.

4.11.3.2 Except at branch junctions, the sustained combined stress (see 4.11.2(c)) is that due to pressure and deadweight only and the bending and torsional stresses obtained from expressions (31), (33) and (34) and equation (35) shall for this consideration, therefore, be those attributable to deadweight only.

4.11.3.3 A typical sequence of calculations required in a flexibility analysis, together with the conditions/criteria applicable to each stage, are summarized in the flow chart given in appendix G.

* For worked example of stress calculation of sectionalized pipe, see appendix F.

4.11.4 Stress evaluation on straights and bends

4.11.4.1 Combined stress f_c . The combined stress value f_c (in N/mm^2) on straights and bends including mitred bends shall be calculated from:

$$f_c = \sqrt{F^2 + 4f_s^2} \quad (28)$$

where

F is the greater of f_T or f_L (in N/mm^2);

where

f_T is the transverse stress (i.e. transverse pressure stress + transverse bending stress) (in N/mm^2), see 4.11.4.2;

f_L is the longitudinal stress (i.e. longitudinal pressure stress + longitudinal bending stress) (in N/mm^2), see 4.11.4.3;

f_s is the torsional stress (in N/mm^2), see 4.11.4.4.

NOTE. For mitred bends within the limits of this standard $f_T > f_L$.

4.11.4.2 Transverse stress f_T . The transverse stress f_T (in N/mm^2) shall be calculated as follows.

(a) The transverse pressure stress on both straights and bends excluding mitred bends shall be calculated from:

$$\frac{pd}{2t} + 0.5p \quad (29)$$

(b) The transverse pressure stress on mitred bends shall be calculated from:

$$\left\{ \frac{pd}{2t} + 0.5p \right\} \left\{ 1 + 0.6427 \tan \alpha \sqrt{\frac{(d+t)}{2t}} \right\} \quad (30)$$

(c) The transverse bending stress on a straight pipe shall be taken as zero.

(d) Transverse bending stress at bends including mitred bends shall be calculated from:

$$\frac{r}{I} \sqrt{(M_i F_{Ti})^2 + (M_o F_{To})^2} \quad (31)$$

For (a), (b) and (d) above

d is the mean inside diameter (in mm);

t is the mean thickness (in mm);

p is the design pressure (in N/mm^2);

M_i is the maximum in-plane bending moment (in $\text{N}\cdot\text{mm}$);

M_o is the maximum out-of-plane bending moment (in $\text{N}\cdot\text{mm}$);

F_{Ti} is the in-plane transverse stress intensification factor for bends from figure 4.11.1(3), and, for mitred bends, from figure 4.11.1(8) line A;

F_{To} is the out-of-plane transverse stress intensification factor for bends from figure 4.11.1(5), and, for mitred bends, from figure 4.11.1(8) line A;

r is the mean radius of the pipe (in mm);

I shall be calculated from:

$$I = \frac{\pi (D^4 - d^4)}{64}$$

where

D is the mean outside diameter;

d is the mean inside diameter

as defined in 1.3.2;

α is as shown in figure 4.3.2.2.

4.11.4.3 Longitudinal stress f_L . The longitudinal stress f_L (in N/mm^2) shall be calculated as follows.

(a) The longitudinal pressure stress on both straights and bends including mitred bends shall be calculated from:

$$\frac{pd^2}{4t(d+t)} \quad (32)$$

(b) The longitudinal bending stress on a straight pipe shall be calculated from:

$$\frac{d+2t}{2I} \sqrt{M_i^2 + M_o^2} \quad (33)$$

(c) The longitudinal bending stress at bends including mitred bends shall be calculated from:

$$\frac{r}{I} \sqrt{(M_i F_{Li})^2 + (M_o F_{Lo})^2} \quad (34)$$

where

F_{Li} is the in-plane longitudinal stress intensification factor for bends from figure 4.11.1(2), and, for mitred bends, from figure 4.11.1(8) line B;

F_{Lo} is the out-of-plane longitudinal stress intensification factor for bends from figure 4.11.1(4), and, for mitred bends, from figure 4.11.1(8) line B;

4.11.4.4 Torsional stress f_s . The torsional stress f_s (in N/mm^2) on both straights and bends including mitred bends shall be calculated from:

$$f_s = \frac{M_t(d+2t)}{4I} \quad (35)$$

where

M_t is the torsional moment (in $\text{N}\cdot\text{mm}$).

4.11.5 Stress evaluation at branch junction

4.11.5.1 Combined stress f_{CB} . The combined stress f_{CB} (in N/mm^2) at branch junctions shall be considered separately at connections 1, 2 and 3 (see figure 4.11.5.1) and shall be calculated from:

$$f_{CB} = q \sqrt{f_B^2 + 4f_{SB}^2} \quad (36)$$

where

f_B is the transverse pressure stress at the junction plus non-directional bending stress (in N/mm^2);

f_{SB} is the torsional stress at the junction (in N/mm^2);

q is the relaxation factor used in hot stress evaluation only (see 4.11.3.1(b));

$q = 0.5$ for d_2/d_1 ratios in excess of 0.3;

$q = 0.44$ for d_2/d_1 ratios equal to or less than 0.3;

$d_{2\gamma}$ is the mean inside diameter of the branch (in mm) multiplied by $1/\sin \gamma$; where γ is defined as the angle between the branch and the main (as defined in 4.8.5.1);

d_1 is the mean inside diameter of the main (in mm).

NOTE. This method of calculating the combined stress may, in some instances, give over pessimistic results. An alternative more accurate method of calculation applicable to a limited range of branch types and geometries is presented in appendix H. Otherwise a comprehensive design by analysis may be undertaken in accordance with appendix J. Use of these alternative methods in preference to the method presented in this clause shall be at the discretion of the designer.

4.11.5.2 Transverse pressure stress. The transverse pressure stress (in N/mm^2) at branch junction shall be calculated from:

$$\frac{(d_1 + t_a) p m}{2 t_a} \quad (37)$$

(see notes 1, 2 and 3)

where

t_a is the actual minimum thickness of the main at the branch junction, i.e. minimum measured thickness where the pipe is available or ordered thickness less tube maker's tolerance (in mm);

p is the design pressure (in N/mm^2);

m is the stress multiplier equal to:

(a) for branch junctions where both r_2/r_1 and t_2/t_1 are equal to or less than 0.3:

$$m = 1.8 + \frac{2.8 r_2}{r_1} \sqrt{\frac{r_1}{t_1 n}} \quad (38)$$

(b) for branch junctions where either or both of the ratios r_2/r_1 and t_2/t_1 are greater than 0.3, m can be obtained from figure 4.11.5.2 by entering at Z_1 ,

where:

$$Z_1 = \left(\frac{r_2}{t_2} \right)^2 \frac{t_1}{n r_1} \quad (39)$$

For (a) and (b) above

r_1 is the mean radius of the main at the junction, based on mean thickness (in mm);

r_2 is the mean radius of the branch at the junction, based on mean thickness (in mm);

t_1 is the mean thickness of the main at the junction with the branch (in mm);

t_2 is the mean thickness of the branch at the junction with the main (in mm);

$n = 1$ for branches not deemed to be interacting in accordance with 4.8.4. For interacting branches n is as defined in 4.8.5.2

NOTE 1. The values of m designated in this standard pertain to fabricated full penetration welded or non-protruding set in or homogeneous branches where any necessary reinforcement for pressure containment is incorporated in the thickness of the main and/or branch.

Where the branch is not of the type defined in note 1 and/or when reinforcement is not as defined in note 1, the m value shall be the estimated pressure peak stress at the junction, divided by the mean diameter hoop stress of the unpierced main.

NOTE 2. 4.8.3 permits the use of other forms of reinforcement subject to the agreement of the purchaser and the manufacturer, and also subject to the use of such reinforcement being substantiated by relevant service experience or by experimental or theoretical analysis.

Where the peak stress cannot be defined from theoretical analysis or alternatively from experimental data, the transverse pressure stress shall be considered as not less than:

2.2 f where $d_{2\gamma}/d_1$ is greater than 0.3; or

2.5 f where $d_{2\gamma}/d_1$ is equal to or less than 0.3;

where

f is the design stress in accordance with 3.2.

NOTE 3. The value of transverse pressure stress so obtained is not intended to indicate the maximum peak stress obtaining, but is so defined as to put a limit on external loading being carried by the junction.

NOTE 4. Stiffening pads may be used to reduce bending stresses.

4.11.5.3 Non-directional bending stress. The non-directional bending stress at branch junctions shall be the greatest value applicable to connection 1, 2 or 3 (see figure 4.11.5.1), determined as follows.

(a) The bending stress at branch junction from connection 1 or 2 shall be calculated from:

$$\frac{r_1}{I} \sqrt{(M_i B_i)^2 + (M_o B_o)^2} \quad (40)$$

where

M_i is the in-plane moment from connection 1 or 2 according to the case (in $\text{N}\cdot\text{mm}$);

M_o is the out-of-plane moment from connection 1 or 2 according to the case (in $\text{N}\cdot\text{mm}$);

B_i is the in-plane branch stress intensification factor from figure 4.11.1(6) (see note 4 to 4.11.5.2);

B_o is the out-of-plane branch stress intensification factor from figure 4.11.1(6) (see note 4 to 4.11.5.2);

r_1 is as defined in 4.11.5.2;

I shall be calculated from:

$$I = \frac{\pi (D^4 - d^4)}{64}$$

where

D is the mean outside diameter of the main;

d is the mean inside diameter of the main as defined in 1.3.2;

(b) The bending stress at branch junction from connection 3 shall be calculated as for connections 1 and 2, but with M_i and M_o applicable to connection 3 and with r_2 substituted for r_1 (r_2 , t_1 and t_2 being as defined in 4.11.5.2). The value of I shall be calculated from either $I = \pi r_2^3 t_2 B_o$ or $I = \pi r_2^3 t_1$ whichever gives the lower value.

(c) Torsional stress f_{SB} at branch junction shall be the value applicable to connection 1, 2 or 3.

NOTE. Torsional stress is as defined in equation (35), where t , d and I are values applicable to the branch being considered.

4.12 Drainage

4.12.1 General

Every precaution shall be taken in the layout of steam pipework to prevent the formation of water during operation or when shut down.

Provision shall be made for water, whether formed continuously or occasionally, to be efficiently removed from the system and for the required warming up rates to be achieved.

NOTE. To assist in the correct design of the system, the purchaser's enquiry specification should state drainage flows for any mode of operation.

As far as is practicable, the drainage water shall not be allowed to come into contact with metal at a higher temperature.

4.12.2 Fall

A suitable fall shall be provided in the main pipework to ensure that the water flows towards the drainage point and, where practicable, this fall shall be in the direction of the steam flow.

The drain lines shall be designed to ensure drainage by gravity when there is little or no pressure in the main lines and to accommodate any downward movement of the drain connections when thermal expansion of the mains takes place.

NOTE 1. Sag due to dead weight, the direction of steam flow, its velocity and the quantity of condensate should be taken into account when considering the fall. Where drainage is with the flow of steam, a fall of not less than 1 in 100 is recommended. Where drainage is against the flow of steam, a fall of not less than 1 in 40 is recommended.

Small pipes such as gauge connections, which might act as reflux condensers, shall be arranged to ensure that any condensate which is formed will be re-evaporated before it can enter the larger and hotter pipe.

NOTE 2. This may be done by nesting the smaller pipe against the larger under the lagging or by the provision of perforated internal pipe suitably arranged within an annulus branch.

4.12.3 Drainage points

Steam pipework shall be provided with adequate draining points wherever water can collect under working conditions. Such provision shall take the form of drainage pockets which shall be connected to steam traps or other suitable apparatus which will ensure the prompt discharge of water from the system.

NOTE. It is recommended that a bypass be fitted to each system trap and, to reduce the likelihood of dirt accumulating in the trap, consideration should be given to an arrangement which enables debris to be ejected through the bypass valve.

Water may collect in various portions of the pipework due to valve leakage or other causes, when shut down or when warming up and these points shall be provided with hand drains.

Steam velocity and quantity of condensate shall be taken into account when considering the bore of the drainage pocket which shall be not less than 25% of the main pipe bore. The take-off from such pockets shall be

situated well above the bottom of the pocket to minimize the possibility of scale blocking the drain pipe. Such pockets shall have either flanged or welded closures to permit cleaning when necessary.

Where pipelines which may be subject to sub-atmospheric pressure have drains connected to an atmospheric drain vessel as an alternative discharge, then a valve or other device shall be provided to isolate the direction connection to the atmospheric drain vessel when the pipelines are at subatmospheric pressure.

4.12.4 Drain branches

Drain branches shall be provided with suitable means of controlling or isolating the drain flow, such as orifice plates, isolating valves or traps depending on the type of system to be drained. Where two valves in series are used, the upstream 'Master' valve shall be of the parallel slide type and the downstream 'Martyr' valve shall be of the globe or other type suitable for flow regulation.

4.12.5 Flexibility of drain lines

Sufficient flexibility shall be provided in the drain lines to cater for the thermal movements of the main as well as those of the drain lines themselves.

4.12.6 Boiler and high pressure pipework drain vessels and vents

4.12.6.1 Drain vessels and their associated vent pipes shall be suited to the onerous conditions imposed by the discharge of large volumes of steam to atmosphere, the design taking into account the kinetic energy and the enthalpy of the steam.

Drain systems with drain vessels, provided with orifices where necessary, shall be so designed that the vessel with its vent and drainage arrangements are capable of handling the maximum drainage flow that can be discharged into it under any mode of operation.

4.12.6.2 The shell thickness shall be suitable for the loads imposed, particularly at inlet connections and where supports apply concentrated loads to the shell.

NOTE. In general, a thickness to diameter ratio of about 1 to 100 will be adequate to withstand the onerous conditions at such positions.

The vessel shall be constructed in accordance with BS 5500; the design temperature shall be the basis for establishing the construction category.

4.12.6.3 Where inlet branches are subject to vibration, provision shall be made for this in the design.

4.12.6.4 The design of vent pipe guides and supports shall be such as to allow the free expansion of the vent pipe when operating at full temperature conditions, which may reach to within 85 °C of the highest temperature of the system being drained.

Vents and silencers shall be designed for the maximum flow rate envisaged under any mode of operation.

The thickness to diameter ratio of vent pipework shall be not less than 1 to 150.

4.13 Pipework supports

4.13.1 General

Pipe supports shall comply with BS 3974, where applicable.

NOTE. The term 'supports', in the context of 4.13, refers to the entire range of the various methods of carrying the weight of pipework and associated equipment (valves, strainers, flanges, etc.). It also includes those elements used to anchor, restrain, direct or absorb piping movement.

4.13.2 Loads on supports

In addition to the weight effects of piping components, the design of supports shall take into account the weight of insulation and the fluid carried and other load effects caused by pressure, wind, vibration and shock. Supports shall also be capable of carrying the total load under commissioning and test conditions unless additional temporary support is provided during these periods.

Where anchors, guides or limit stops are fitted to restrain, direct or absorb piping movements, the design shall take into account the forces and moments generated at these elements by weight, thermal expansion, internal pressure, wind, vibration and shock effects.

4.13.3 Design of supports

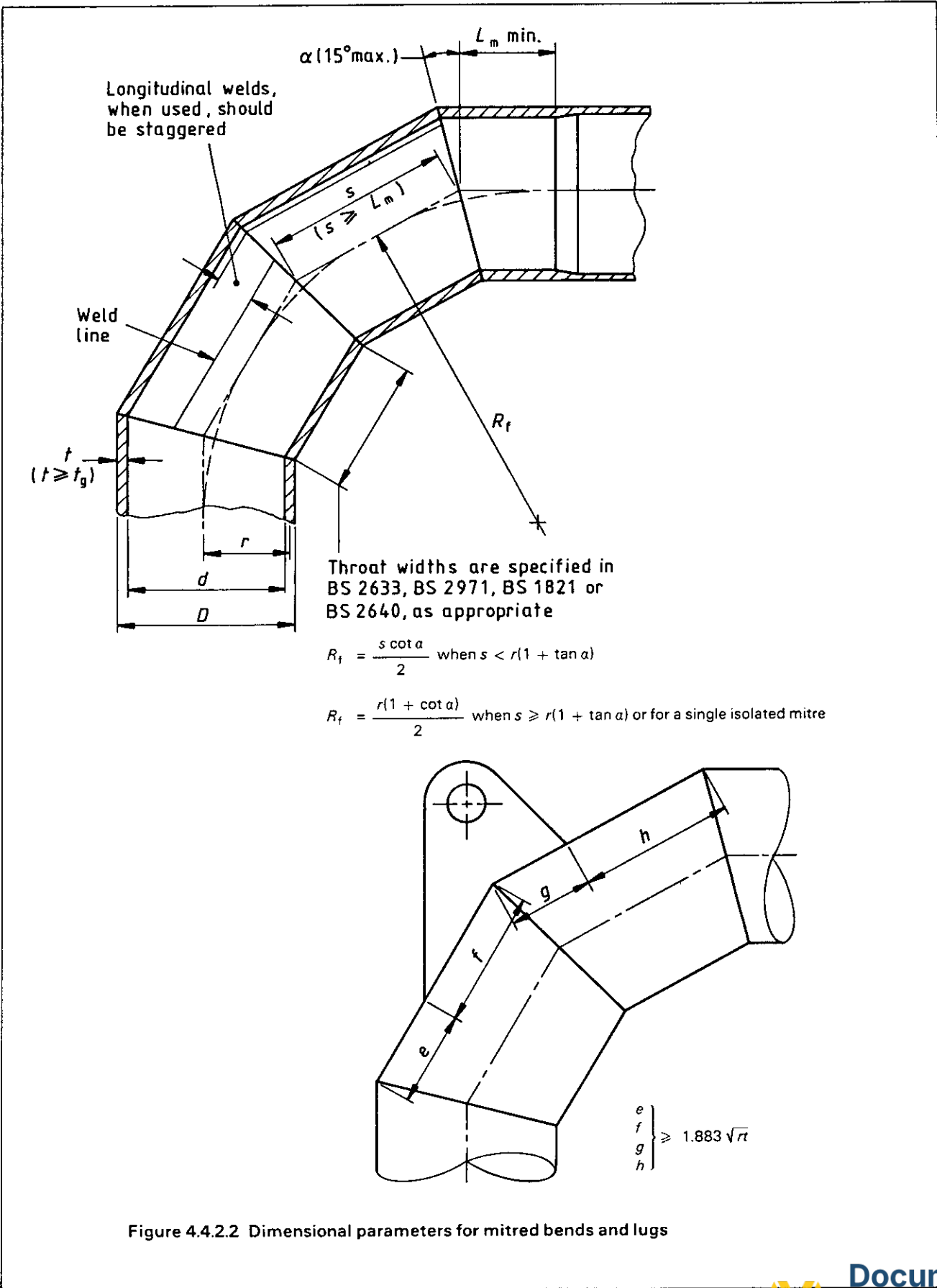
Supports shall be capable of carrying the sum of all the concurrently acting loads. They shall be designed to provide the required supporting effect and shall permit free movement for expansion and contraction unless specially designed to restrain, direct or absorb such movement. The design of pipe clips or other pipe attachments shall be such as to prevent damage to insulation.

The use of constant-effort support hangers is recommended at locations where appreciable thermal deflections occur and such supports shall not have a deviation in supporting effort, including friction, of more than $\pm 5\%$ of the specified load at any point in their travel except where the end forces have to be kept within close limits (see 1.4.2.2(d)), when the deviation shall not be more than $\pm 2.5\%$. The deviation quoted relates to the support on test when the rod is in the vertical position. Provision shall be made for in situ load adjustment of at least $\pm 20\%$ of the specified load.

For variable spring supports, consideration shall be given to the change of spring effort due to pipe deflection and its effect on the support load and forces on the connecting plant and pipework.

Support spacing shall be such as to prevent detrimental bending and shear stresses in the pipework. Particular consideration shall be given where components, e.g. flanges and valves, imposed concentrated loads. Deflections shall be such that the operation of the equipment is not impaired. Where supports include, for example, brackets, lugs, rings welded directly to pipework, localized stresses shall be assessed.

NOTE. The procedures in appendices A and G of BS 5500 : 1991 give guidance in this respect.



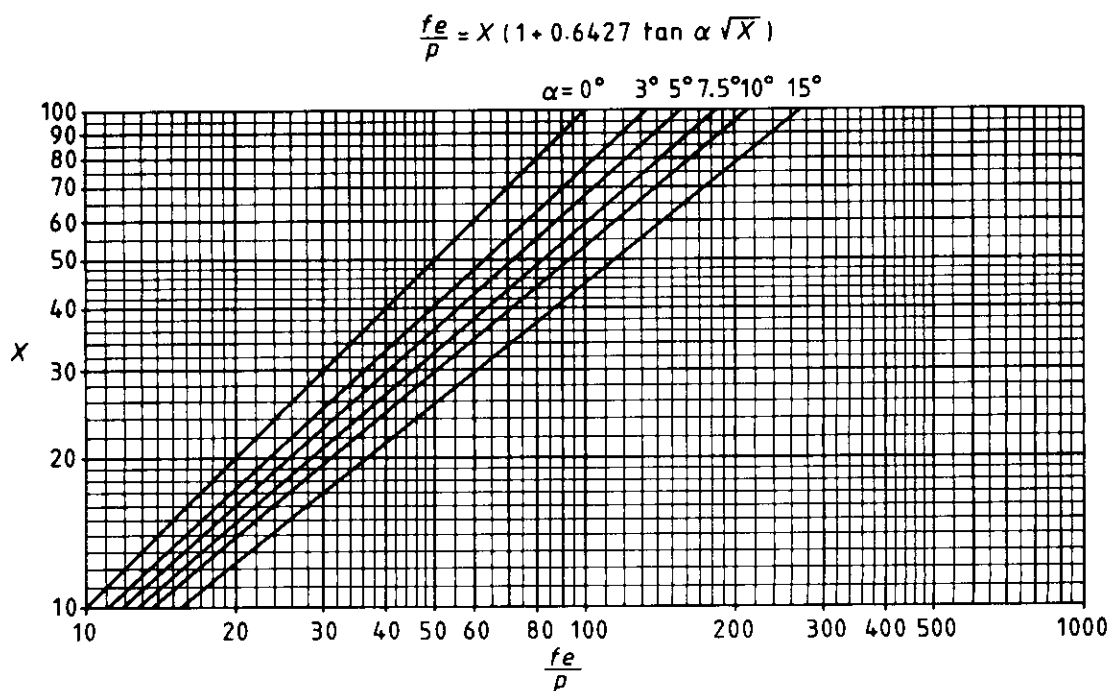
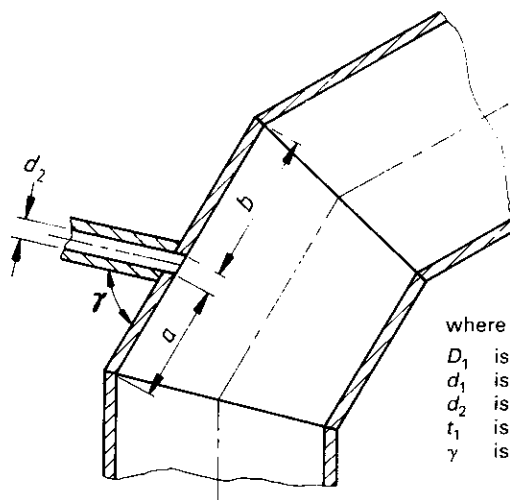


Figure 4.4.2.4 X values required to satisfy mitred bend design requirements

$$d_2 \leq \frac{d_1}{10}$$

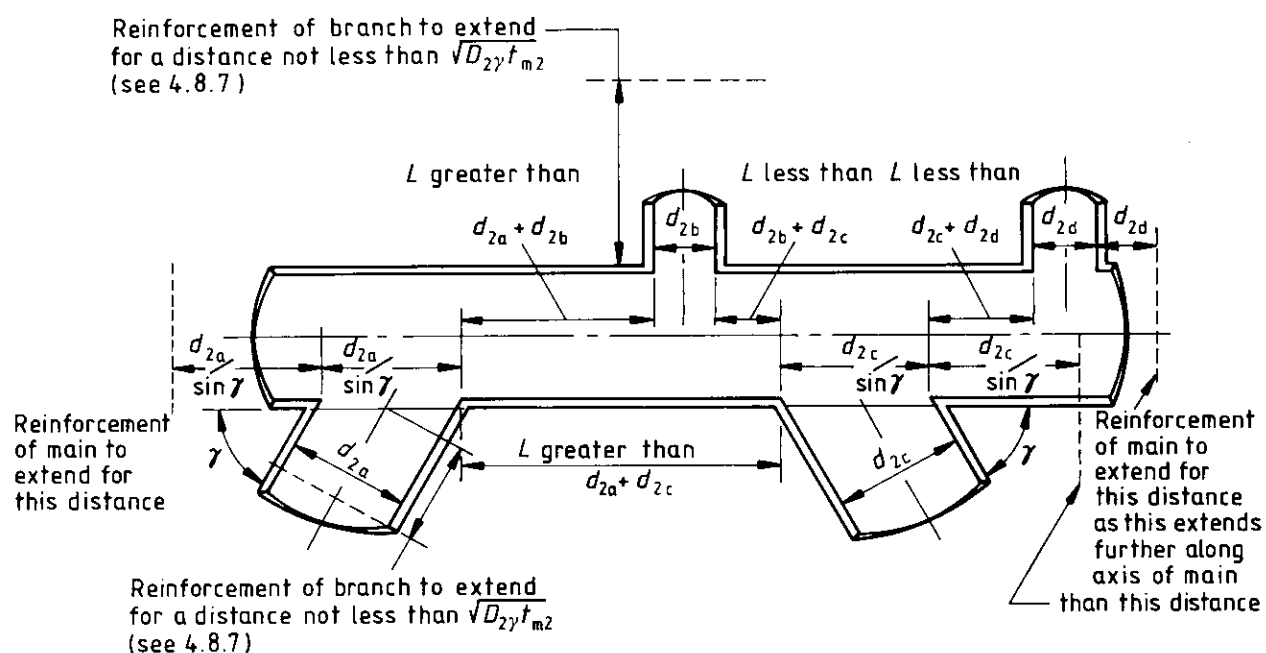
$$a \text{ and } b \geq 1.833 \sqrt{(d_1 + t_1) \times t_1 / 2} \text{ or } 1.833 \sqrt{(D_1 - t_1) \times t_1 / 2}, \text{ and } \frac{d_2}{\sin \gamma}$$



where

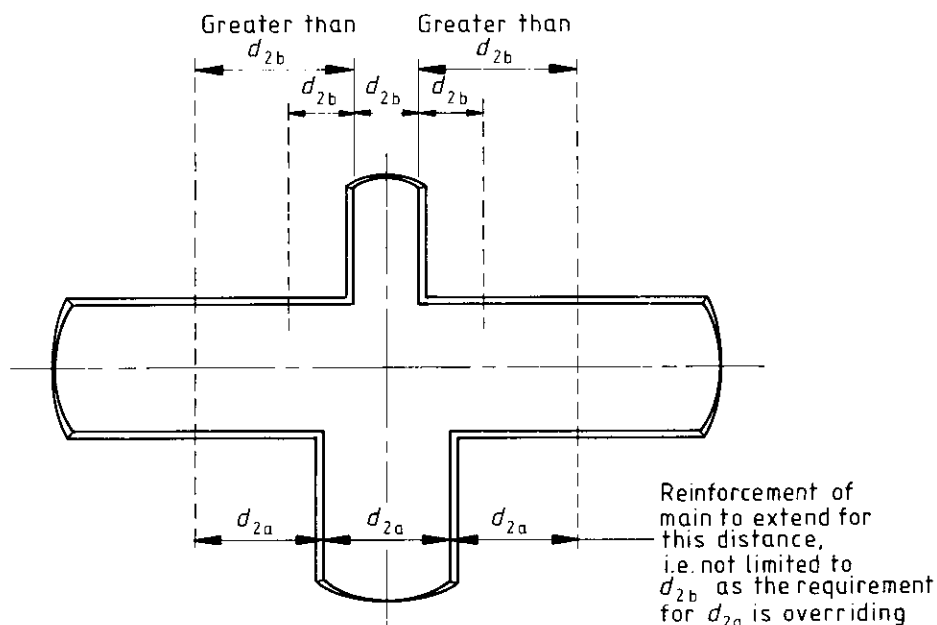
- D_1 is the mean outside diameter of the main (in mm);
- d_1 is the mean inside diameter of the main (in mm);
- d_2 is the mean inside diameter of the branch (in mm);
- t_1 is the mean thickness of the main (in mm);
- γ is the angle between branch and main (in degrees).

Figure 4.8.2 Dimensional parameters for branch connections to mitred gusseted bends



d_{2a} is unaffected by other branches
 d_{2b} is affected by d_{2c}
 d_{2c} is affected by d_{2b} and d_{2d}
 d_{2d} is affected by d_{2c}

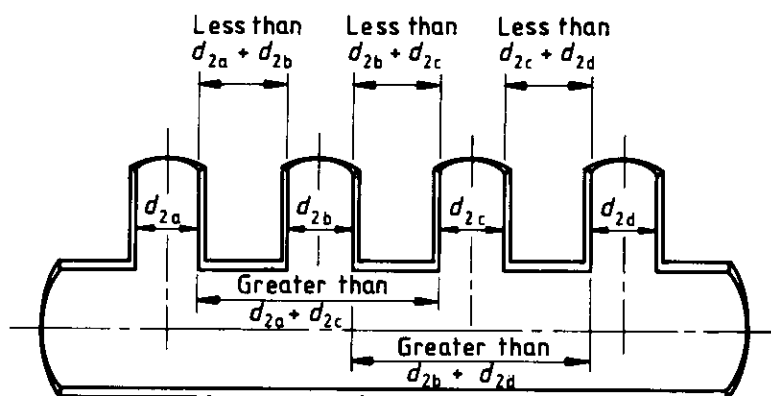
(a)



d_{2a} and d_{2b} form a pair affecting each other

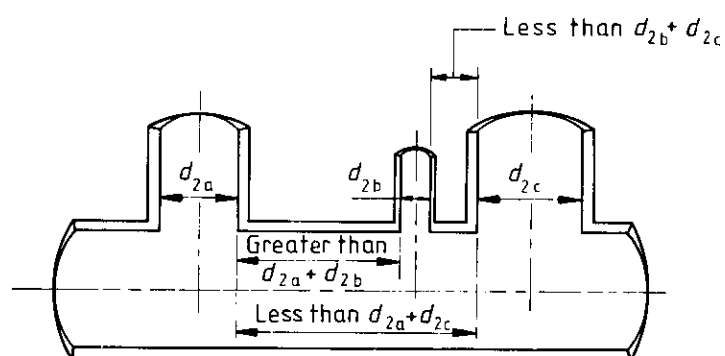
(b)

Figure 4.8.4 Typical branch pipes



d_{2a} is affected by d_{2b}
 d_{2d} is affected by d_{2c}
 d_{2b} is affected by d_{2a} and d_{2c}
 d_{2c} is affected by d_{2b} and d_{2d}

(c)



d_{2a} is affected by d_{2c}
 d_{2b} is affected by d_{2c}
 d_{2c} is affected by d_{2a} and d_{2b}

(d)

Figure 4.8.4 (concluded)

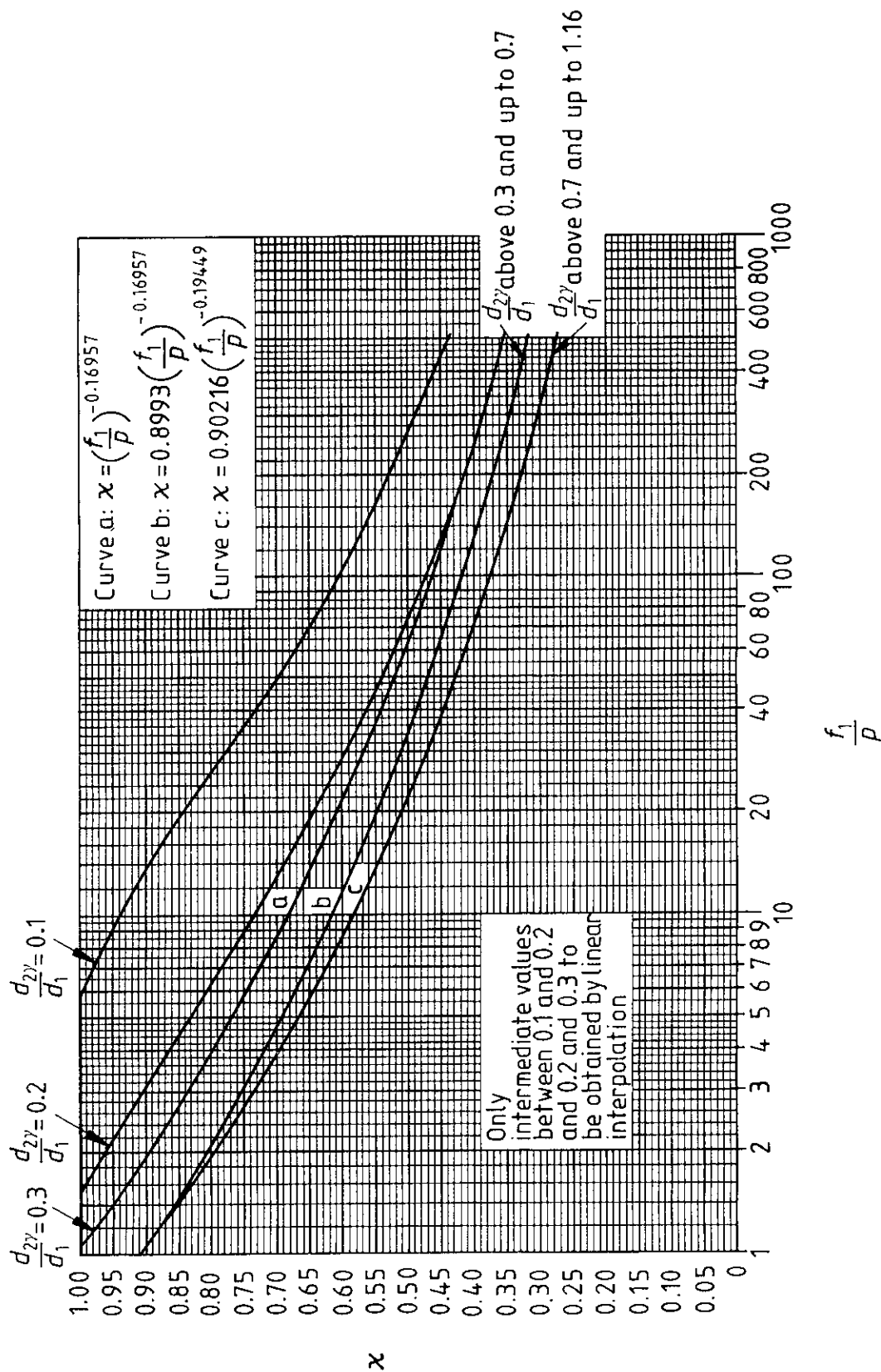


Figure 4.8.5.1 Reinforcement of branch pipes ($x : f_1/p$)

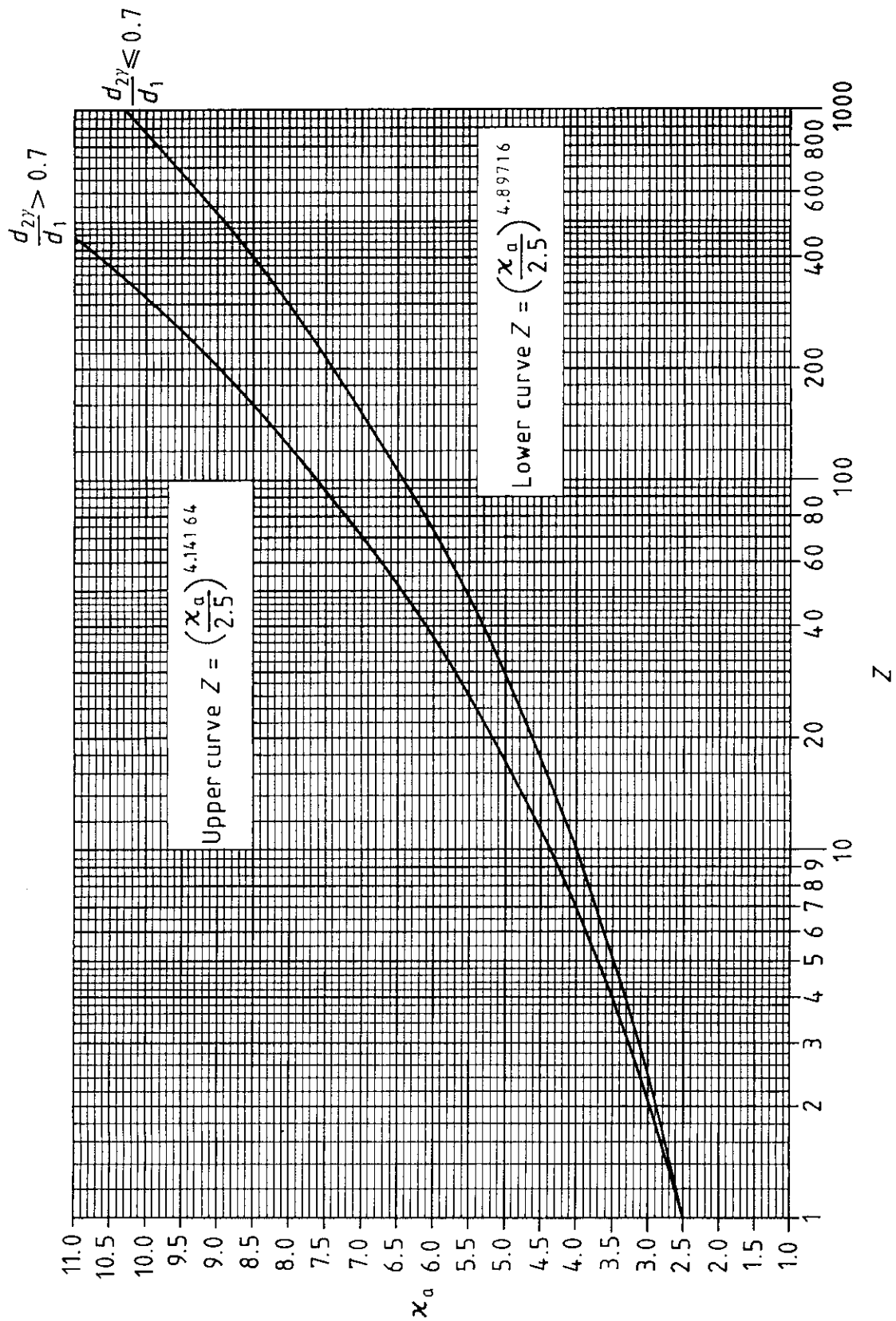


Figure 4.8.5.2(1) Reinforcement of branch pipes ($x_a : Z$)

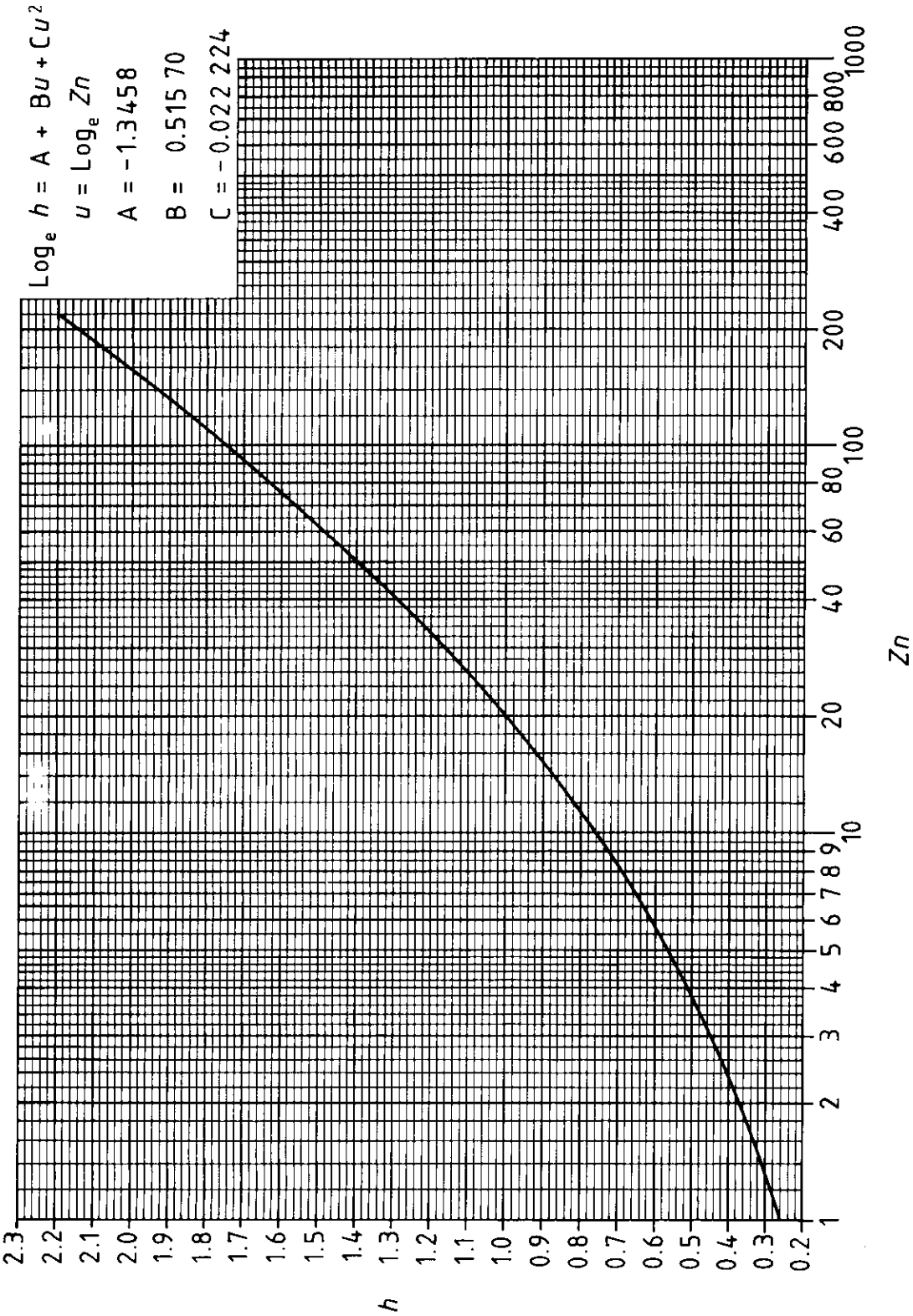


Figure 4.8.5.2(2) Reinforcement of branch pipes ($h : Zn$)

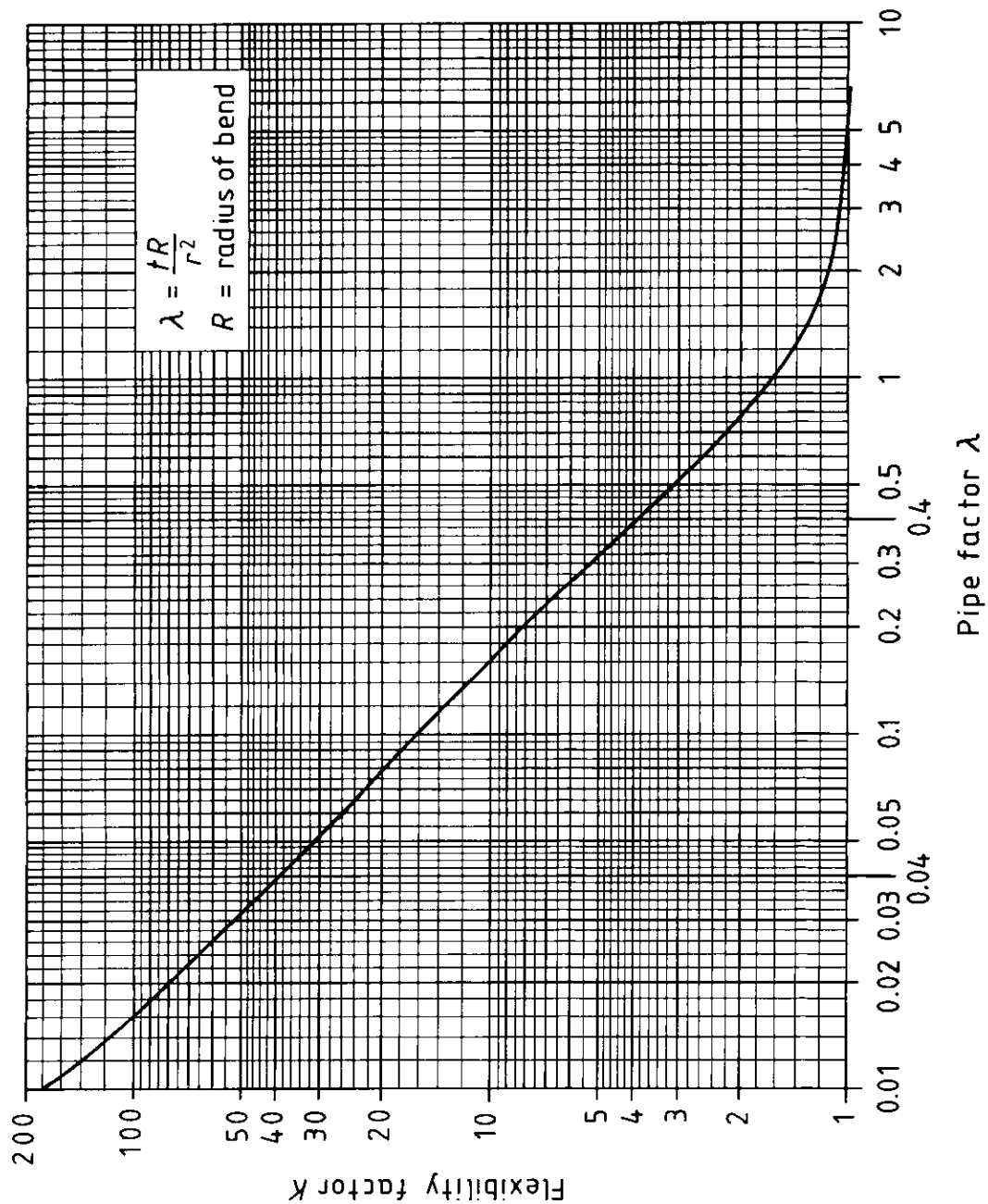


Figure 4.11.1(1) Flexibility factor in- and out-of-plane (bends)