BRITISH STANDARD

BS 806 : 1993

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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BSI STANDARDS

Committees responsible for this British Standard

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Associated Offices Technical Committee
BEAMA Ltd.
British Compressed Gases Association
British Fire Protection Systems Association Ltd.
British Gas plc
British Steel Industry
Copper Development Association
Electricity Association
Energy Industries Council
Engineering Equipment and Materials Users Association
Health and Safety Executive
Lloyds Register Engineering Services
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Contents

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 It supersedes the 1990 edition which is withdrawn.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 bar = 0.1 N/mm^2 = 100 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/mm^2)
- f maximum permissible design stress (in N/mm^2)
- P_t hydraulic test pressure (in N/mm^2)

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 exeed 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:

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

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:

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

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 piping 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:

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

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.

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/mm^2 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/mm^2 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/mm²) 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	480		
Carbon	BS 3601	ERW	320		130	119	108	97	86	77	71	69	69	68										4
Carbon	BS 3601	ERW, S	360	≤ 16	154	140	126	111	96	86	79	77	76	75										4
		S		40	150	136	122	109																
		S		65	143	131	119	107																
Carbon	BS 3601	ERW, S		≤ 16	183	166	149	132	115	103	95	91	90	89										4
		S	430	40	177	162	146	131																
		S		65	170	156	143	129																
Carbon	BS 3601	SAW		≤ 16	183	166	149	132	115															1,4
			430	40	177	162	146	131																
				65	170	156	143	129																
Carbon	BS 3602: Part 1	HFS, CFS	360	≤ 16	153	139	125	117	111	97	87	82	80	78	77	77	76	69	60	52	44	36	100 000	4
		ERW, CEW															74	65	56	48	40	32	150 000	
		HFS, CFS		40	150	137											71	62	53	45	37	28	200 000	
		HFS, CFS		65	143	134											68	59	51	42	35	26	250 000	
Carbon	BS 3602: Part 1	HFS, CFS		≤ 16	183	166	149	135	120	109	101	97	96	95	95	88	79	69	60	52	44	36	100 000	
		ERW, CEW	430												93	83	74	65	56	48	40	32	150 000	
		HFS, CFS		40	177	163									90	80	71	62	53	45	37	28	200 000	
		HFS, CFS		65	170	161									87	78	68	59	51	42	35	26	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	
														125	111	95	81	68	58	50	43	38	150 000	
														121	104	88	75	63	54	46	40	34	200 000	
														115	98	83	70	59	51	43	37	32	250 000	
Carbon	BS 3602: Part 2	LAW	430	≤ 16	167	158	149	135	120	109	101													
				40	160	155																		
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/mm²) 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	620		
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	
																	111	102	83	67	55	44	35	29	24						150 000	
																	111	94	76	61	49	40	32	26	22						200 000	
																	107	88	70	57	45	37	30	25	20						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	
																		100	83	67	55	44	35	29	24						150 000	
																		94	76	61	49	40	32	26	22						200 000	
																		88	70	57	45	37	30	25	20						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	
																		133	122	106	92	80	69	59	47						150 000	
																		132	115	100	87	75	65	55							200 000	
																		128	111	96	83	72	62	50							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			100 000	2,6
															133	122	108	97	85	73	63	56	48	42	36	31	27	23			150 000	
															130	117	104	92	79	68	59	52	45	38	33	28	25	22			200 000	
															126	113	100	87	75	65	57	49	42	36	32	27	23	20			250 000	
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	
																		184	168	152	135	115	98	85	72	62	52	44	37	30	150 000	
																		180	164	146	128	110	94	80	68	58	49	41	34	28	200 000	
																		176	160	142	124	105	90	77	65	55	46	38	32	25	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/mm²) 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	750		
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*			100 000	
																		82	*72*	*61*	*51*	*46*	*42*	*36*	*31*				150 000	
																		81	*69*	*58*	*48*	*44*	*40*	*34*	*30*				200 000	
																		78	*66*	*55*	*46*	*42*	*38*	*33*	*29*				250 000	
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*	100 000	6
																			85	*66*	*52*	*46*	*41*	*32*	*25*	*19*	*16*		150 000	
																			79	*62*	*48*	*43*	*38*	*29*	*22*	*18*	*15*		200 000	
																			75	*58*	*45*	*40*	*35*	*27*	*22*	*18*	*15*		250 000	
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/mm²) 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	630	640	650	660	680	700	720	740	750		
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*				100 000	
															102	*101*	*93*	*78*	*64*	*49*	*42*	*36*	*32*	*27*						150 000	
															102	*97*	*89*	*74*	*58*	*45*	*38*	*33*	*28*	*25*						200 000	
															100	*93*	*85*	*71*	*55*	*42*	*35*	*31*	*26*	*22*						250 000	
Austenitic	BS 3605 : Part 1	HFS, CFM, HFM	321 S51 (1105)	130	116	103	98	93	87	84	82	79	77			76		76	75	*68*	*60*	*55*	*49*	*44*	*34*	*26*				100 000	
																			75	*62*	*56*	*50*	*44*	*38*	*29*					150 000	
																			72	*58*	*52*	*46*	*41*	*35*	*27*					200 000	
																			68	*55*	*49*	*44*	*38*	*33*	*25*					250 000	
Austenitic	BS 3605 : Part 1	HFS, CFM, HFM	347 S31	163	155	146	138	135	130	124	122	119																			
Austenitic	BS 3605 : Part 1	HFS, CFM, HFM	347 S51	163	155	146	138	135	130	124	122	119	119		117	117	116	*99*	*82*	*66*	*59*	*53*	*47*	*41*	*31*	*23*	*17*			100 000	
																117	*112*	*93*	*75*	*61*	*54*	*48*	*42*	*37*	*28*	*22*				150 000	
																116	*106*	*88*	*72*	*58*	*51*	*45*	*39*	*34*	*25*	*19*				200 000	
																112	*102*	*85*	*68*	*55*	*48*	*42*	*37*	*32*	*24*	*19*				250 000	
Austenitic	BS 3605 : Part 1	HFS, CFS, HFM	215 S15	180	168	156	144	141	139	136	135	133	132			130			126	124	123	*107*	*87*	*71*	*52*	*40*				100 000	
																				124	*114*	*93*	*75*	*62*	*46*	*35*				150 000	
																				124	*104*	*83*	*67*	*56*	*42*	*32*				200 000	
																				118	*96*	*76*	*62*	*52*	*40*					250 000	

Table 3.2 Design stress values *(continued)*

(b) Steel castings

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	390	400	410	420	430	440	450	460	470	480	490	500	510	520	530	540	550	560	570	580		
Carbon	BS 1504	161-430A	153	139	126	119	115	104	95		87																				7
Carbon	BS 1504	161-430E	153	139	126	119	115	104	95		93	93	92	84	71	60	51	44	37											100 000	7
												93	89	75	63	54	46	38	30											150 000	
												92	82	69	58	49	42	34												200 000	
												88	78	65	54	46	38													250 000	
Carbon	BS 1504	161-480A	163	153	143	136	128	115	105	101																					7
Carbon	BS 1504	161-480E	163	153	143	136	128	115	109	107	107	106	99	84	71	60	51	44	37											100 000	7
											107	100	89	75	63	54	46	38	30											150 000	
											103	92	82	69	58	49	42	34												200 000	
											99	88	78	65	54	46	38													250 000	
Carbon	BS 1504	161-540A	186	176	165	154	144	130	119		109																				7
Alloy	BS 1504	245E	173	167	161	155	140	121	116		113					110		109	108	95	78	62	51	41	32					100 000	7
																			107	88	70	57	46	37	30					150 000	
																			100	81	65	53	42	35	28					200 000	
																			95	77	62	50	40	32	25					250 000	
Alloy	BS 1504	621A	187	175	161	146	141	136	123		114					108				102	100	93	76	62	52	42	33	27		100 000	7
																					100	83	67	55	44	35	29	24		150 000	
																					94	76	61	49	40	32	26	22		200 000	
																					88	70	57	45	37	30	25	20		250 000	
Alloy	BS 1504	660A	196	180	168	156	145	137	128		118					112					106										7
Alloy	BS 1504	622E	217	212	208	203	197	193	187		182			176	174	170	153	137	120	107	95	85	76	65	61	53	45	39	34	100 000	2, 6, 7
															174	161	144	129	112	98	88	77	68	63	56	48	41	36	31	150 000	
															172	156	139	124	107	94	83	71	63	59	52	45	38	33	28	200 000	
															170	152	135	119	103	91	79	68	60	57	49	42	36	32	27	250 000	

Table 3.2 Design stress values *(continued)*

(b) Steel castings *(concluded)*

Material	Casting standard	Steel grade	Values of *f* (N/mm²) for design temperatures (°C) not exceeding: 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	Design lifetime h	Notes
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		114	113	113	109	99	91	82	74	66	53	41	35	31	22		100 000	7, 10
														113	112	102	93	84	75	68	61	48	37	32	28	22		150 000	
														113	106	98	88	79	72	64	58	45	34	29	25	19		200 000	
														112	102	94	85	76	68	61	55	42	32	28	24	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/mm²) 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	164	≤ 100	203	187	171	156	142	128	121	116	115	114	105	90	77	65	56	48	42	100 000	8
			150	187	173	159	145	137					111	95	81	68	58	50	43	38	150 000	
													104	88	75	63	54	46	40	34	200 000	
													98	83	70	59	51	43	37	32	250 000	
Carbon	BS 1503	221-410	≤ 100	143	134	125	121	112	100	95	92	92	92	92	90	77	65	56	48	42	100 000	8
			> 100	137	126	116	113	108						92	81	68	58	50	43	38	150 000	
														88	75	63	54	46	40	34	200 000	
														83	70	59	51	43	37	32	250 000	
Carbon	BS 1503	221-430	≤ 100	150	141	133	129	119	107	102	99	99	99	98	90	77	65	56	48	42	100 000	8
			> 100	143	133	124	121	115					99	95	81	68	58	50	43	38	150 000	
													99	88	75	63	54	46	40	34	200 000	
													98	83	70	59	51	43	37	32	250 000	
Carbon	BS 1503	221-460	≤ 100	163	154	145	140	129	117	112	109	108	108	105	90	77	65	56	48	42	100 000	8
			> 100	157	146	135	131	125					108	95	81	68	58	50	43	38	150 000	
													104	88	75	63	54	46	40	34	200 000	
													98	83	70	59	51	43	37	32	250 000	
Carbon	BS 1503	221-490	≤ 100	177	167	157	151	140	128	122	119	118	118	105	90	77	65	56	48	42	100 000	8
			> 100	170	158	146	141	135				118	111	95	81	68	58	50	43	38	150 000	
												118	104	88	75	63	54	46	40	34	200 000	
												115	98	83	70	59	51	43	37	32	250 000	
Carbon	BS 1503	221-510	≤ 100	190	177	165	159	147	135	129	125	124	121	105	90	77	65	56	48	42	100 000	8
												124	111	95	81	68	58	50	43	38	150 000	
												121	104	88	75	63	54	46	40	34	200 000	
												115	98	83	70	59	51	43	37	32	250 000	
Carbon	BS 1503	223-410	≤ 100	163	150	138	130	120	106	99	93	92	92	91	90	77	65	56	48	42	100 000	8
			> 100	153	141	129	121	115						91	81	68	58	50	43	38	150 000	
														88	75	63	54	46	40	34	200 000	
														83	70	59	51	43	37	32	250 000	
Carbon	BS 1503	223-430	≤ 100	173	160	148	139	128	114	107	101	100	99	98	90	77	65	56	48	42	100 000	8
			> 100	163	149	134	129	123					99	95	81	68	58	50	43	38	150 000	
													99	88	75	63	54	46	40	34	200 000	
													98	83	70	59	51	43	37	32	250 000	

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

Material	Forging standard	Steel grade	Ruling Section mm	Values of *f* (N/mm²) for design temperatures (°C) not exceeding: 50	100	150	200	250	300	350	390	400	410	420	430	440	450	460	470	480	Design lifetime h	Notes
Carbon	BS 1503	223-460	⩽ 100	193	179	164	151	140 }	127	119	113	111	110	*105*	*90*	*77*	*65*	*56*	*48*	*42*	100 000	8
			> 100	180	166	153	141	135 }					110	*95*	*81*	*68*	*58*	*50*	*43*	*38*	150 000	
													104	*88*	*75*	*63*	*54*	*46*	*40*	*34*	200 000	
													98	*83*	*70*	*59*	*51*	*43*	*37*	*32*	250 000	
Carbon	BS 1503	223-490	⩽ 100	209	194	179	165	152 }	139	131	125	123	*121*	*105*	*90*	*77*	*65*	*56*	*48*	*42*	100 000	8
			> 100	197	182	167	153	146 }				123	*111*	*95*	*81*	*68*	*58*	*50*	*43*	*38*	150 000	
												121	*104*	*88*	*75*	*63*	*54*	*46*	*40*	*34*	200 000	
												115	*98*	*83*	*70*	*59*	*51*	*43*	*37*	*32*	250 000	
Carbon	BS 1503	223-510	⩽ 100	217	203	190	173	159	147	138	132	131	*121*	*105*	*90*	*77*	*65*	*56*	*48*	*42*	100 000	8
												128	*111*	*95*	*81*	*68*	*58*	*50*	*43*	*38*	150 000	
												121	*104*	*88*	*75*	*63*	*54*	*46*	*40*	*34*	200 000	
												115	*98*	*83*	*70*	*59*	*51*	*43*	*37*	*32*	200 000	
Carbon	BS 1503	224-410	⩽ 100	157	146	136	125	114 }	101	94	90	89	88	88	88	*77*	*65*	*56*	*48*	*42*	100 000	8
			> 100	147	137	127	117	109 }						88	*81*	*68*	*58*	*50*	*43*	*38*	150 000	
														88	*75*	*63*	*54*	*46*	*40*	*34*	200 000	
														83	*70*	*59*	*51*	*43*	*37*	*32*	250 000	
Carbon	BS 1503	224-430	⩽ 100	167	156	145	133	121 }	108	101	97	96	95	95	*90*	*77*	*65*	*56*	*48*	*42*	100 000	8
			> 100	157	146	135	123	117 }						95	*81*	*68*	*58*	*50*	*43*	*38*	150 000	
														88	*75*	*63*	*54*	*46*	*40*	*34*	200 000	
														83	*70*	*59*	*51*	*43*	*37*	*32*	250 000	
Carbon	BS 1503	224-460	⩽ 100	183	170	157	145	132 }	118	111	106	105	105	104	*90*	*77*	*65*	*56*	*48*	*42*	100 000	8
			> 100	170	158	147	135	127 }					105	*95*	*81*	*68*	*58*	*50*	*43*	*38*	150 000	
													104	*88*	*75*	*63*	*54*	*46*	*40*	*34*	200 000	
													98	*83*	*70*	*59*	*51*	*43*	*37*	*32*	250 000	
Carbon	BS 1503	224-490	⩽ 100	203	187	171	156	142 }	128	121	116	115	115	*105*	*90*	*77*	*65*	*56*	*48*	*42*	100 000	8
			> 100	187	173	159	145	137 }				115	*111*	*95*	*81*	*68*	*58*	*50*	*43*	*38*	150 000	
												115	*104*	*88*	*75*	*63*	*54*	*46*	*40*	*34*	200 000	
												115	*98*	*83*	*70*	*59*	*51*	*43*	*37*	*32*	250 000	
Carbon	BS 1503	224-510	⩽ 100	210	194	179	163	149	135	128	124	122	*121*	*105*	*90*	*77*	*65*	*56*	*48*	*42*	100 000	8
												122	*111*	*95*	*81*	*68*	*58*	*50*	*43*	*38*	150 000	
												121	*104*	*88*	*75*	*63*	*54*	*46*	*40*	*34*	200 000	
												115	*98*	*83*	*70*	*59*	*51*	*43*	*37*	*32*	250 000	
Carbon	BS 1503	225-490	⩽ 100	209	199	189	172	160	147 }	137	131	130	*121*	*105*	*90*	*77*	*65*	*56*	*48*	*42*	100 000	8
			> 100	200	187	173	163	154	145 }			128	*111*	*95*	*81*	*68*	*58*	*50*	*43*	*38*	150 000	
												121	*104*	*88*	*75*	*63*	*54*	*46*	*40*	*34*	200 000	
												115	*98*	*83*	*70*	*59*	*51*	*43*	*37*	*32*	250 000	

Table 3.2 Design stress values *(continued)*

(c) Steel forgings *(continued)*

Values of f (N/mm^2) for design temperatures (°C) not exceeding: 50 to 400 °C

Material	Forging standard	Steel grade	Ruling section mm	50	100	150	200	250	300	350	400	Notes
Alloy	BS 1503	620-440		183	166	149	142	131	123	113	108	8
Alloy	BS 1503	620-540	≤ 200	230	224	219	210	202	196	189	186	8
Alloy	BS 1503	621-460		183	173	163	156	145	137	127	122	8
Alloy	BS 1503	660-460		196	190	184	178	161	150	144	139	8
Alloy	BS 1503	271-560		238	229	220	215	208	204	199	192	2, 8
Alloy	BS 1503	622-490		183	176	169	163	157	153	149	145	2, 6, 8
Alloy	BS 1503	622-560		238	231	224	219	213	209	201	197	2,6,8
Alloy	BS 1503	762-690	≤ 250	294	276	259	249	240	233	227	219	8

Values of f (N/mm^2) for design temperatures (°C) not exceeding: 410 to 620 °C

Steel grade	Design lifetime h	410	420	430	440	450	460	470	480	490	500	510	520	530	540	550	560	570	580	590	600	610	620
620-440	100 000					105				101	101	*93*	*76*	*62*	*52*	*42*	*33*	*27*					
620-440	150 000										101	*83*	*67*	*55*	*44*	*35*	*29*	*24*					
620-440	200 000										*94*	*76*	*61*	*49*	*40*	*32*	*26*	*22*					
620-440	250 000										*88*	*70*	*57*	*45*	*37*	*30*	*25*	*20*					
620-540	100 000					182	181	180	*162*	*136*	*112*	*93*	*76*	*62*	*52*	*42*	*33*	*27*					
620-540	150 000						181	174	*149*	*124*	*102*	*83*	*67*	*55*	*44*	*35*	*29*	*24*					
620-540	200 000						181	*162*	*138*	*114*	*94*	*76*	*61*	*49*	*40*	*32*	*26*	*22*					
620-540	250 000						*179*	*155*	*131*	*107*	*88*	*70*	*57*	*45*	*37*	*30*	*25*	*20*					
621-460	100 000					117			115	114	*112*	*93*	*76*	*62*	*52*	*42*	*33*	*27*					
621-460	150 000									114	*102*	*83*	*67*	*55*	*44*	*35*	*29*	*24*					
621-460	200 000									*114*	*94*	*76*	*61*	*49*	*40*	*32*	*26*	*22*					
621-460	250 000									*107*	*88*	*70*	*57*	*45*	*37*	*30*	*25*	*20*					
660-460	100 000					135				134	***133***	***131***	***115***	***100***	***87***	***76***	***66***	***56***					
660-460	150 000										***133***	***122***	***106***	***92***	***80***	***69***	***59***	***47***					
660-460	200 000										***132***	***115***	***100***	***87***	***75***	***65***	***55***						
660-460	250 000										***128***	***111***	***96***	***83***	***72***	***62***	***50***						
271-560	100 000					188	186	*181*	*155*	*129*	*107*	*87*	*69*	*54*	*41*	*30*							
271-560	150 000							*173*	*145*	*118*	*95*	*76*	*60*	*44*	*32*	*23*							
271-560	200 000							*160*	*132*	*108*	*87*	*68*	*51*	*38*	*26*	*18*							
271-560	250 000							*157*	*129*	*105*	*83*	*65*	*48*	*35*	*23*	*14*							
622-490	100 000					137	135	132	*131*	*118*	*105*	*94*	*82*	*72*	*61*	*53*	*45*	*39*	*34*				
622-490	150 000							132	*122*	*108*	*97*	*85*	*73*	*63*	*56*	*48*	*42*	*36*	*31*				
622-490	200 000							*130*	*117*	*104*	*92*	*79*	*68*	*59*	*52*	*45*	*38*	*33*	*28*				
622-490	250 000							*126*	*113*	*100*	*87*	*75*	*65*	*57*	*49*	*42*	*36*	*32*	*27*				
622-560	100 000	196	195	194	*183*	*170*	*157*	*143*	*131*	*118*	*105*	*94*	*82*	*72*	*61*	*53*	*45*	*39*	*34*				
622-560	150 000		195	*186*	*173*	*161*	*148*	*135*	*122*	*108*	*97*	*85*	*73*	*63*	*56*	*48*	*42*	*36*	*31*				
622-560	200 000		195	*182*	*169*	*156*	*143*	*130*	*117*	*104*	*92*	*79*	*68*	*59*	*52*	*45*	*38*	*33*	*28*				
622-560	250 000		*190*	*178*	*165*	*152*	*139*	*126*	*113*	*100*	*87*	*75*	*65*	*57*	*49*	*42*	*36*	*32*	*27*				
762-690	100 000					206				190	187	*173*	*155*	*138*	*122*	*107*	*93*	*80*	*68*	*58*	*48*	*40*	*33*
762-690	150 000										*184*	*168*	*152*	*135*	*115*	*98*	*85*	*72*	*62*	*52*	*44*	*37*	*30*
762-690	200 000										*180*	*164*	*146*	*128*	*110*	*94*	*80*	*68*	*58*	*49*	*41*	*34*	*28*
762-690	250 000										*176*	*160*	*142*	*124*	*105*	*90*	*77*	*65*	*55*	*46*	*38*	*32*	*25*

Table 3.2 Design stress values *(concluded)*
(c) Steel forgings *(concluded)*

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	450	500	520	540	550	560	580	590	600	620	640	650	660	680	700	720		
Austenitic	BS 1503	304 S11		143	127	111	101	95	90	86	81	80																	
Austenitic	BS 1503	304 S31		153	136	119	109	103	98	93	89	87																	
Austenitic	BS 1503	304 S51		153	136	119	109	103	98	93	89	87	85			83	82	82	81	*76*	*65*	*55*	*50*	*45*	*38*	*33*	*28*	100 000	
																		82	*78*	*72*	*61*	*51*	*46*	*42*	*36*	*31*		150 000	
																		81	*75*	*69*	*58*	*48*	*44*	*40*	*34*	*30*		200 000	
																		78	*72*	*66*	*55*	*46*	*42*	*38*	*33*	*29*		250 000	
Austenitic	BS 1503	316 S31 & S33		160	143	127	118	111	106	101	99	96																	
Austenitic	BS 1503	316 S11 & S13		150	134	119	110	103	99	94	91	88																	
Austenitic	BS 1503	316 S51		160	143	127	118	111	106	101	99	96	93			90		89	88	88	*74*	*58*	*53*	*46*	*35*	*28*	*23*	100 000	6
																			88	*85*	*66*	*52*	*46*	*41*	*32*	*25*	*19*	150 000	
																			88	*79*	*62*	*48*	*43*	*38*	*29*	*22*	*18*	200 000	
																			85	*75*	*58*	*45*	*40*	*35*	*27*	*22*	*18*	250 000	
Austenitic	BS 1503	321 S51-490		127	115	103	97	93	87	84	81	79	78			77		76	76	76	*68*	*55*	*49*	*44*	*34*	*26*		100 000	
																			76	*76*	*62*	*50*	*44*	*38*	*29*			150 000	
																			76	*72*	*58*	*46*	*41*	*35*	*27*			200 000	
																			76	*68*	*55*	*44*	*38*	*33*	*25*			250 000	
Austenitic	BS 1503	321 S31		157	145	133	127	121	117	113	110	107																	
Austenitic	BS 1503	321 S51-510		157	145	133	127	121	117	113	110	107	104	103	103	102	102	*86*	*78*	*71*	*57*	*42*	*36*	*31*				100 000	
															103	*101*	*93*	*78*	*72*	*64*	*49*	*36*	*32*	*27*				150 000	
															103	*97*	*89*	*74*	*66*	*58*	*45*	*33*	*28*	*25*				200 000	
															100	*93*	*85*	*71*	*62*	*55*	*42*	*31*	*26*	*22*				250 000	
Austenitic	BS 1503	347 S31		160	151	142	135	127	123	120	118	116																	
Austenitic	BS 1503	347 S51		160	151	142	135	127	123	120	118	116	115		114	113	113	*99*	*91*	*82*	*66*	*53*	*47*	*41*	*31*	*23*		100 000	
																113	*112*	*93*	*84*	*75*	*61*	*48*	*42*	*37*	*28*	*22*		150 000	
																113	*106*	*88*	*79*	*72*	*58*	*45*	*39*	*34*	*25*	*19*		200 000	
																112	*102*	*85*	*76*	*68*	*55*	*42*	*37*	*32*	*24*	*19*		250 000	

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 which 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:

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

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

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

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:

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

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:

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

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:

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

(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:

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

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:

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

Where the inside diameter is the basis for the calculation:

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

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):

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

where

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

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

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/mm^2);
- d is the inside diameter of the pipe (in mm);
- f is the maximum permissible design stress (in N/mm^2) 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).

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.

* 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.

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/mm^2;

(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:

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

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_f, 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:

$$\frac{L}{d_{2m}+d_{2n}} \tag{15}$$

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).

$$t_{m2} = \frac{pD_{2\gamma}}{2f_2e_2x+p} \tag{16}$$

or

$$t_{m2} = \frac{pd_{2\gamma}}{2f_2e_2x-p} \tag{17}$$

$$t_{m1} = \frac{pD_1}{2f_1e_1x+p} \tag{18}$$

or

$$t_{m1} = \frac{pd_1}{2f_1e_1x-p} \tag{19}$$

where

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

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/mm^2) (see **3.2**);

f_2 is the allowable design stress of the branch (in N/mm^2) (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 $d_{2\gamma}/d_1 \leqslant 0.3$ 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**:

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

where

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

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

$$d_2 + t_f \leqslant h\,\delta \qquad (23)$$

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

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;

$$g_1 = 1 - C_1(1 - Y)$$
$$g_2 = 1 - C_2(1 - Y) \qquad (25)$$
$$g_3 = 1 - C_3(1 - Y)$$

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

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));

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

J = 2.2 except where $d_{2\gamma}/d_1 \leqslant 0.3$, 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 $\sqrt{D_{2\gamma}t_{m2}}$ 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 $d_{2\gamma}$. 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.

(a) Wherever possible, piping systems shall be treated as a whole between anchor points.

(b) 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.

(c) 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 $d_2/d_1 \leqslant 0.3$, 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:

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

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:

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

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

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

(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:

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

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 N·mm);

M_o is the maximum out-of-plane bending moment (in N·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:

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

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

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

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

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

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:

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

where

M_t is the torsional moment (in N·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:

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

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 $d_{2\gamma}/d_1$ ratios in excess of 0.3;

q = 0.44 for $d_{2\gamma}/d_1$ 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:

$$\frac{(d_1 + t_a)\,pm}{2t_a} \qquad (37)$$

(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 multipler 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:

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

(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:

$$Z_1 = \left(\frac{r_2}{t_2}\right)^2 \frac{t_1}{nr_1} \qquad (39)$$

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:

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

$2.5f$ 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:

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

where

M_i is the in-plane moment from connection 1 or 2 according to the case (in N·mm);

M_o is the out-of-plane moment from connection 1 or 2 according to the case (in N·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

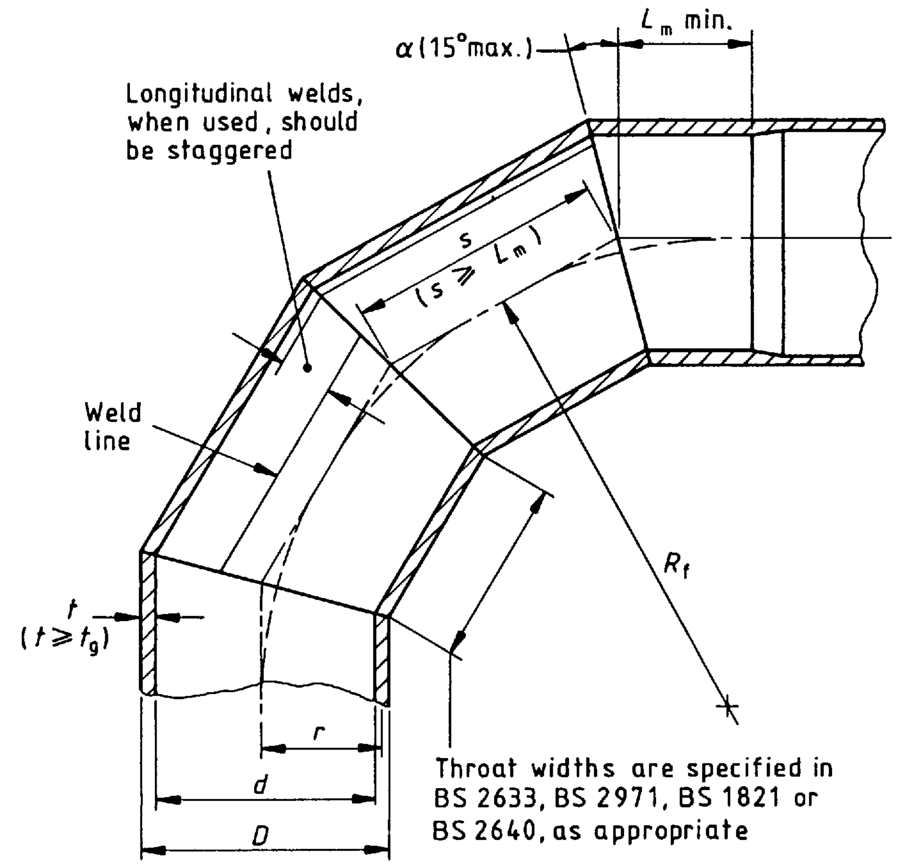
Supports shall be capable of carrying the sum of all the concurrently acting loads. They shall be designed to provide the required supporting effect and shall permit free movement for expansion and contraction unless specially designed to restrain, direct or absorb such movement. The design of pipe clips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

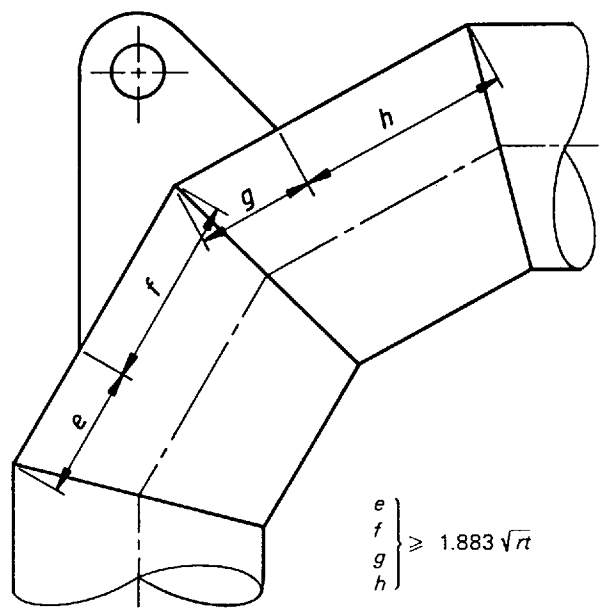
Support spacing shall be such as to prevent detrimental bending and shear stresses in the pipework. Particular consideration shall be given where components, e.g. flanges and valves, imposed concentrated loads. Deflections shall be such that the operation of the equipment is not impaired. Where supports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



$$R_f = \frac{s \cot \alpha}{2} \text{ when } s < r(1 + \tan \alpha)$$

$$R_f = \frac{r(1 + \cot \alpha)}{2} \text{ when } s \geqslant r(1 + \tan \alpha) \text{ or for a single isolated mitre}$$



$$\left.\begin{matrix} e \\ f \\ g \\ h \end{matrix}\right\} \geqslant 1.883\sqrt{rt}$$

Figure 4.4.2.2 Dimensional parameters for mitred bends and lugs

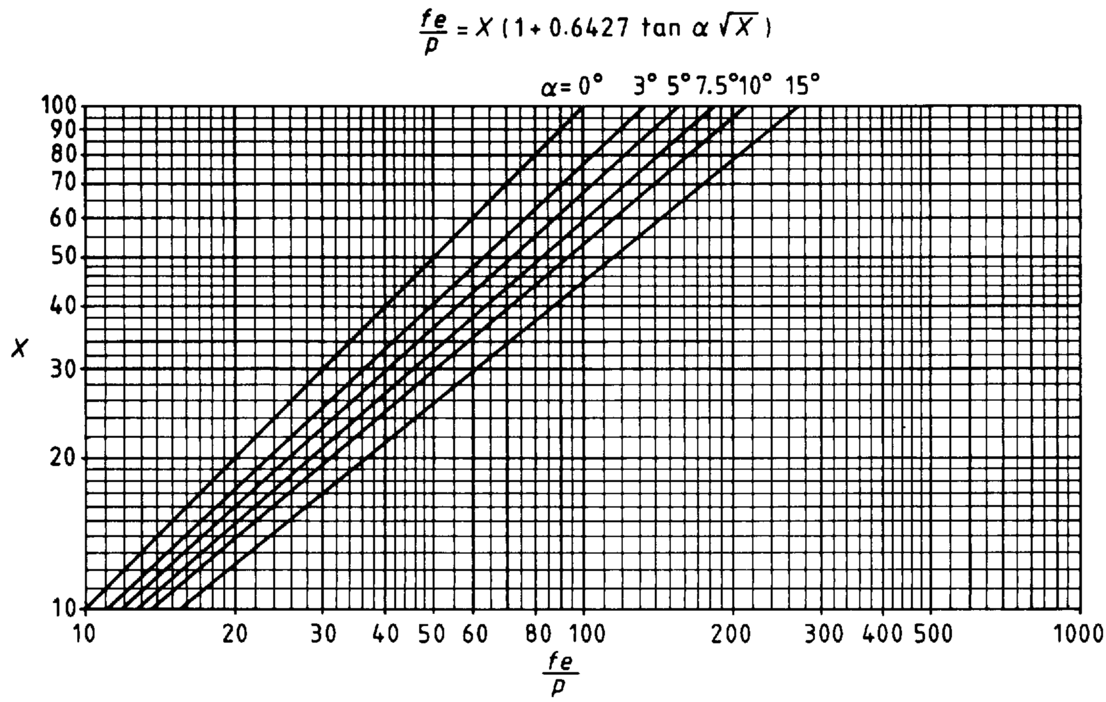
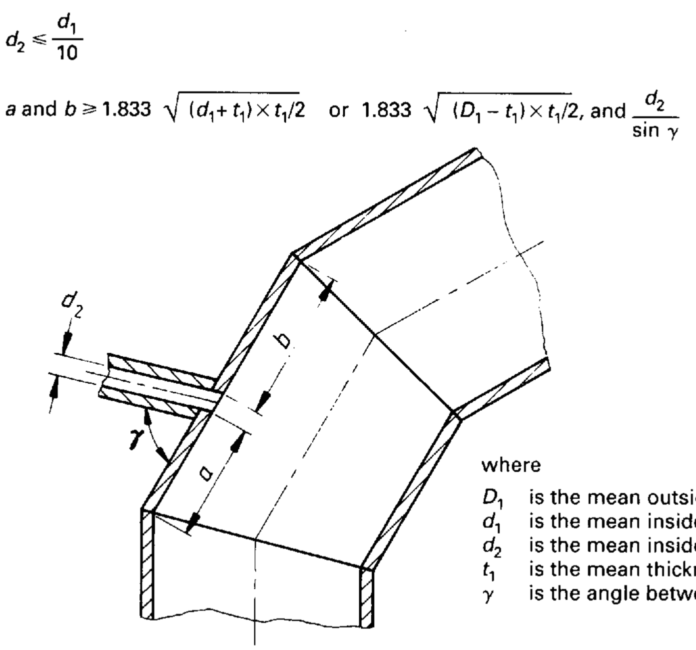


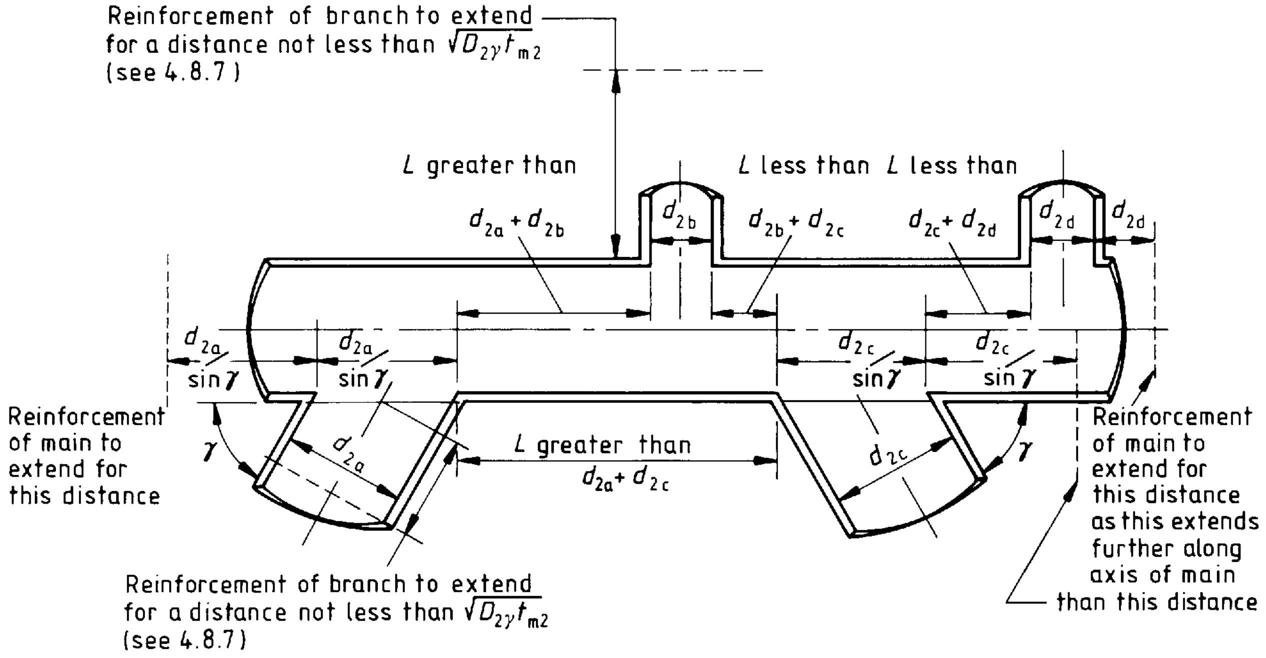
Figure 4.4.2.4 *X* values required to satisfy mitred bend design requirements



where

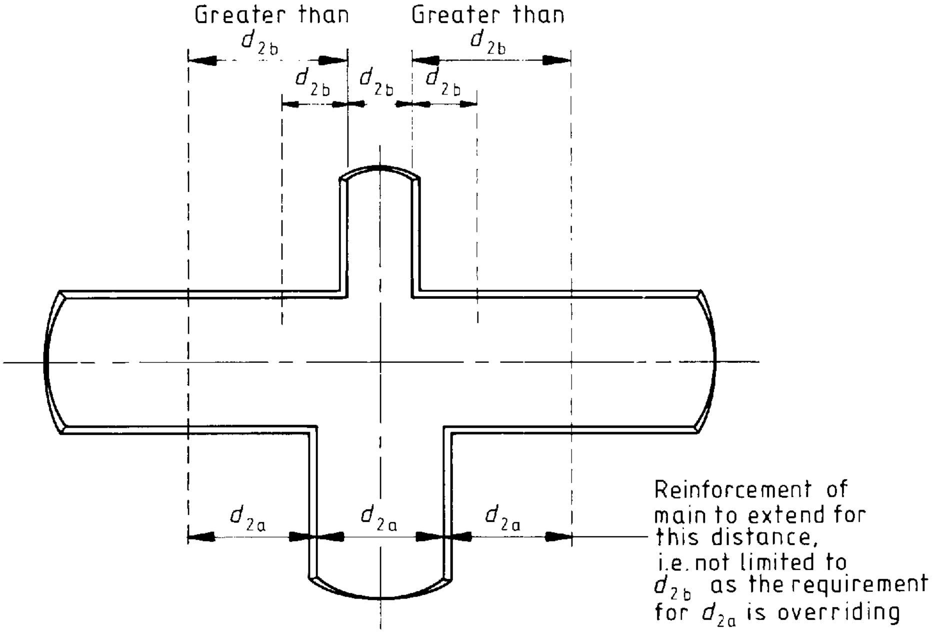
- D_1 is the mean outside diameter of the main (in mm);
- d_1 is the mean inside diameter of the main (in mm);
- d_2 is the mean inside diameter of the branch (in mm);
- t_1 is the mean thickness of the main (in mm);
- γ is the angle between branch and main (in degrees).

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}

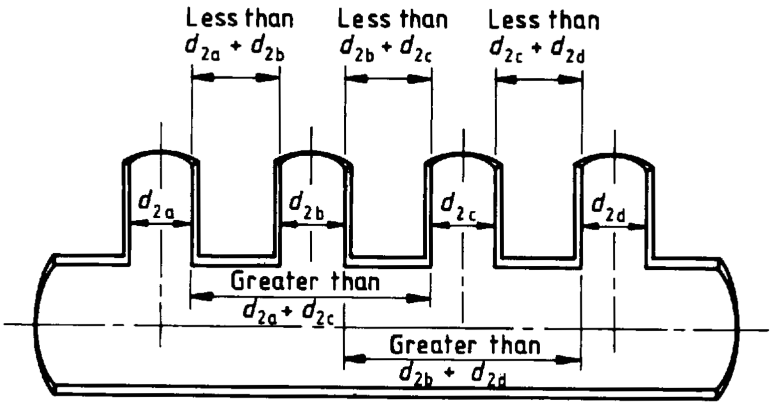
(a)



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

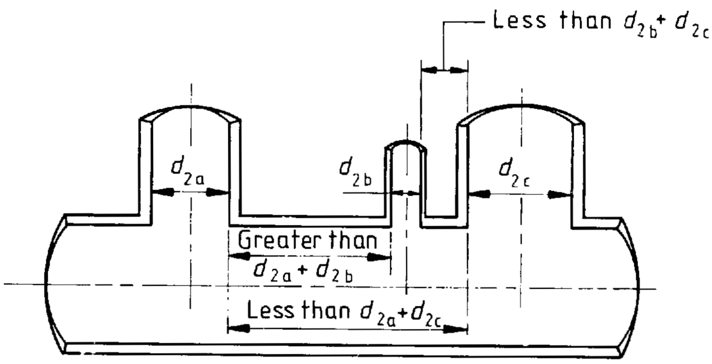
(b)

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)*

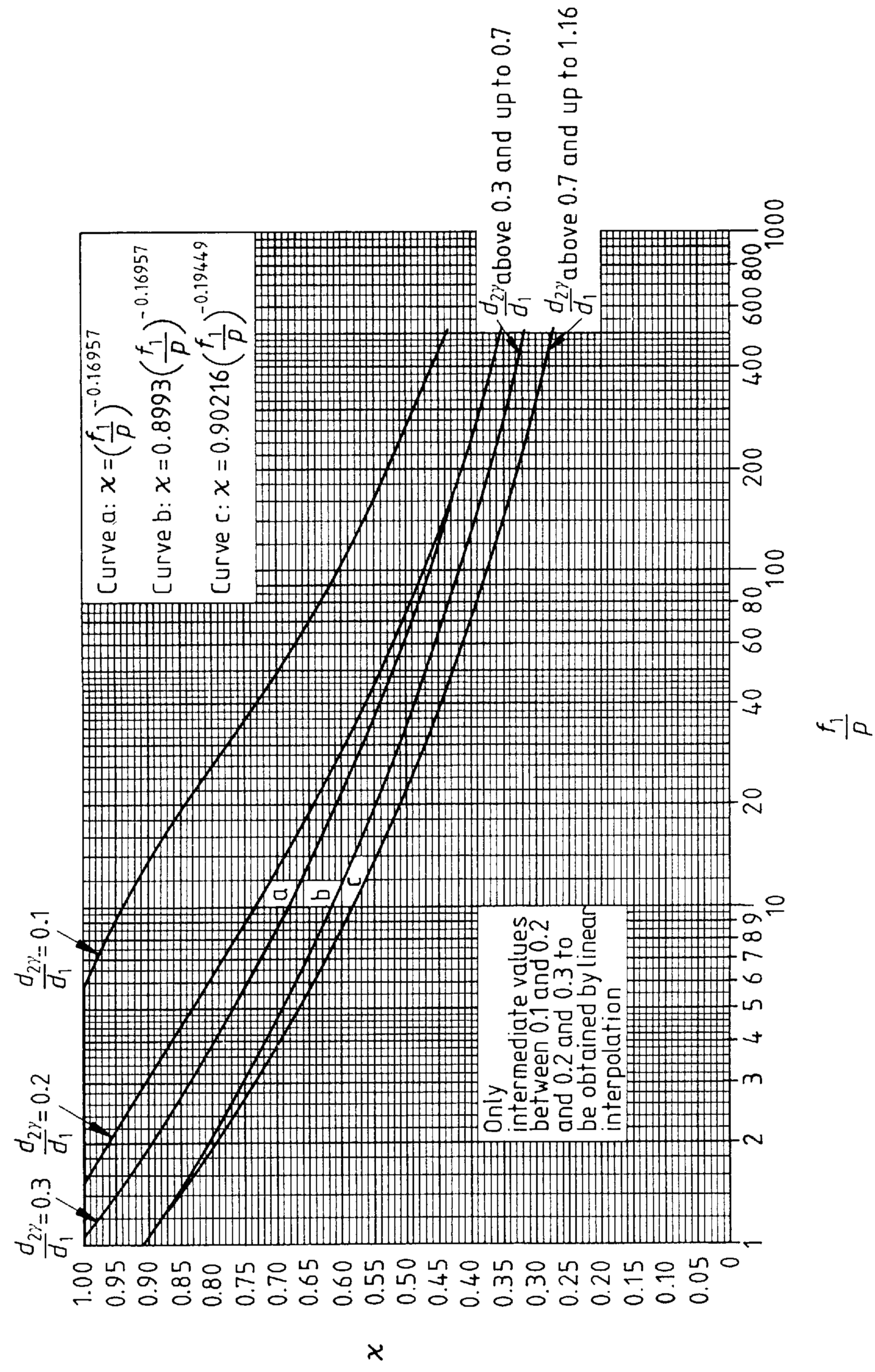


Figure 4.8.5.1 Reinforcement of branch pipes ($x : f_1/p$)

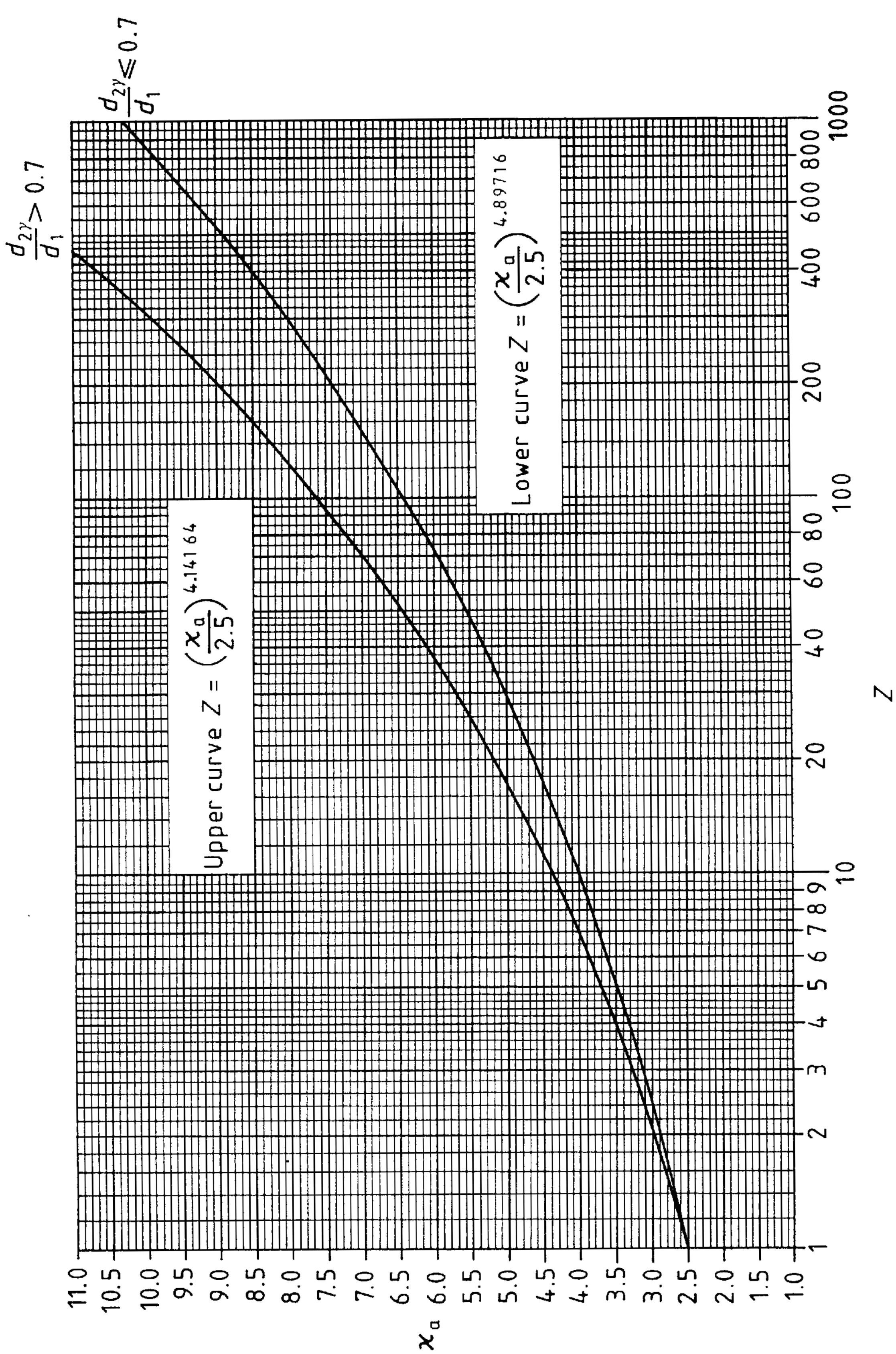


Figure 4.8.5.2(1) Reinforcement of branch pipes ($x_a : Z$)

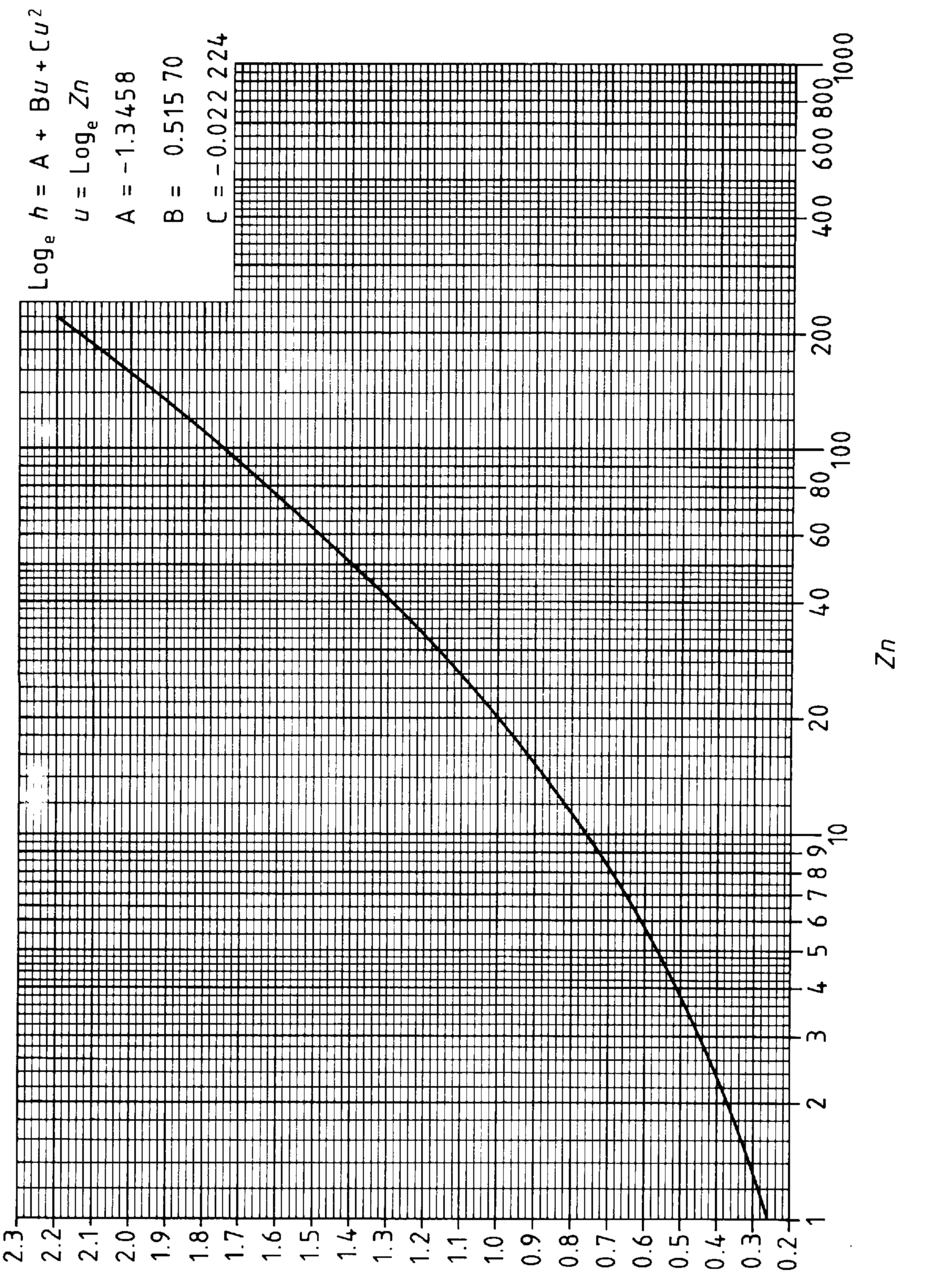


Figure 4.8.5.2(2) Reinforcement of branch pipes (*h* : *Zn*)

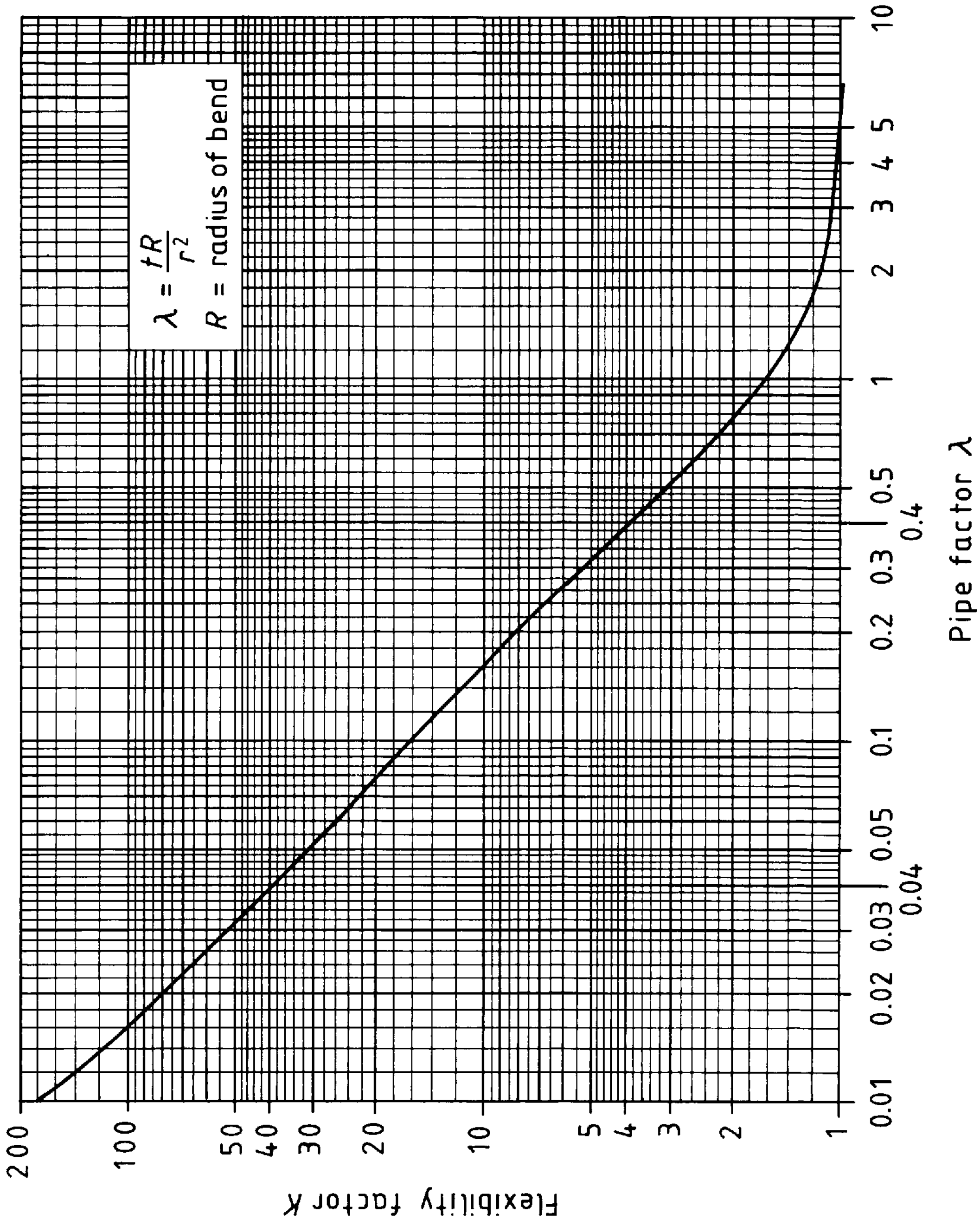


Figure 4.11.1(1) Flexibility factor in- and out-of-plane (bends)

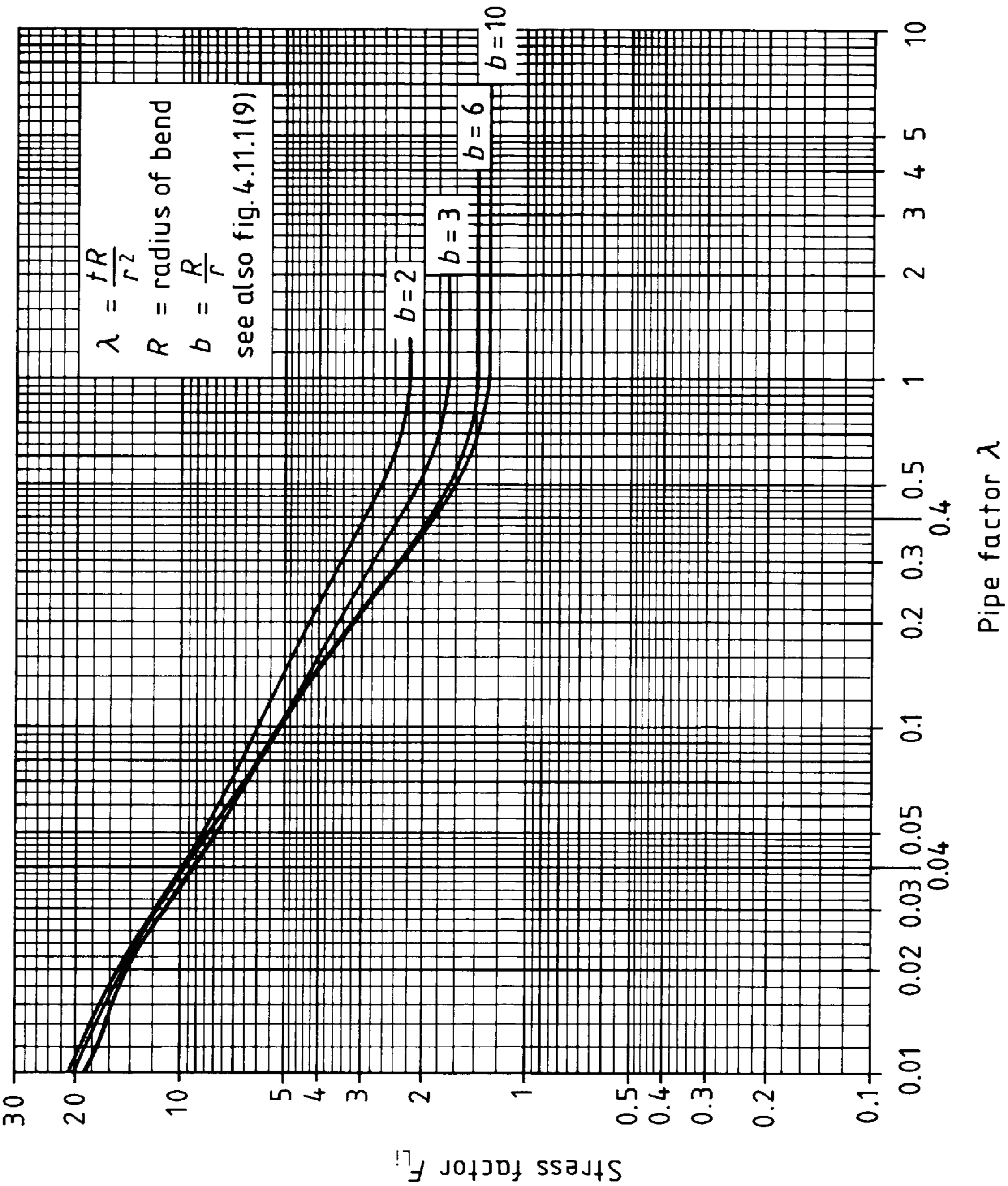


Figure 4.11.1(2) Maximum in-plane longitudinal stress factor (bends)

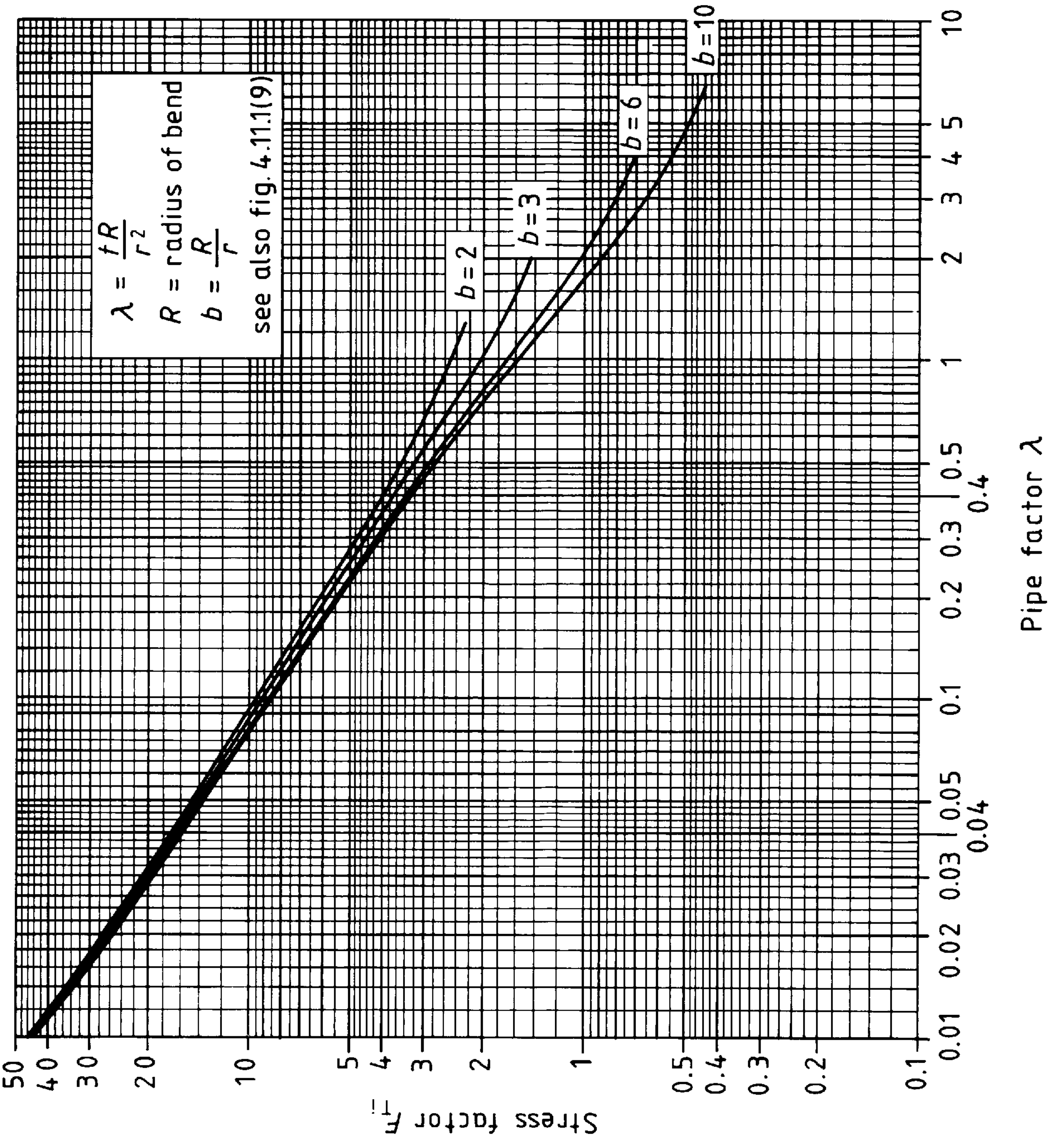


Figure 4.11.1(3) Maximum in-plane transverse stress factor (bends)

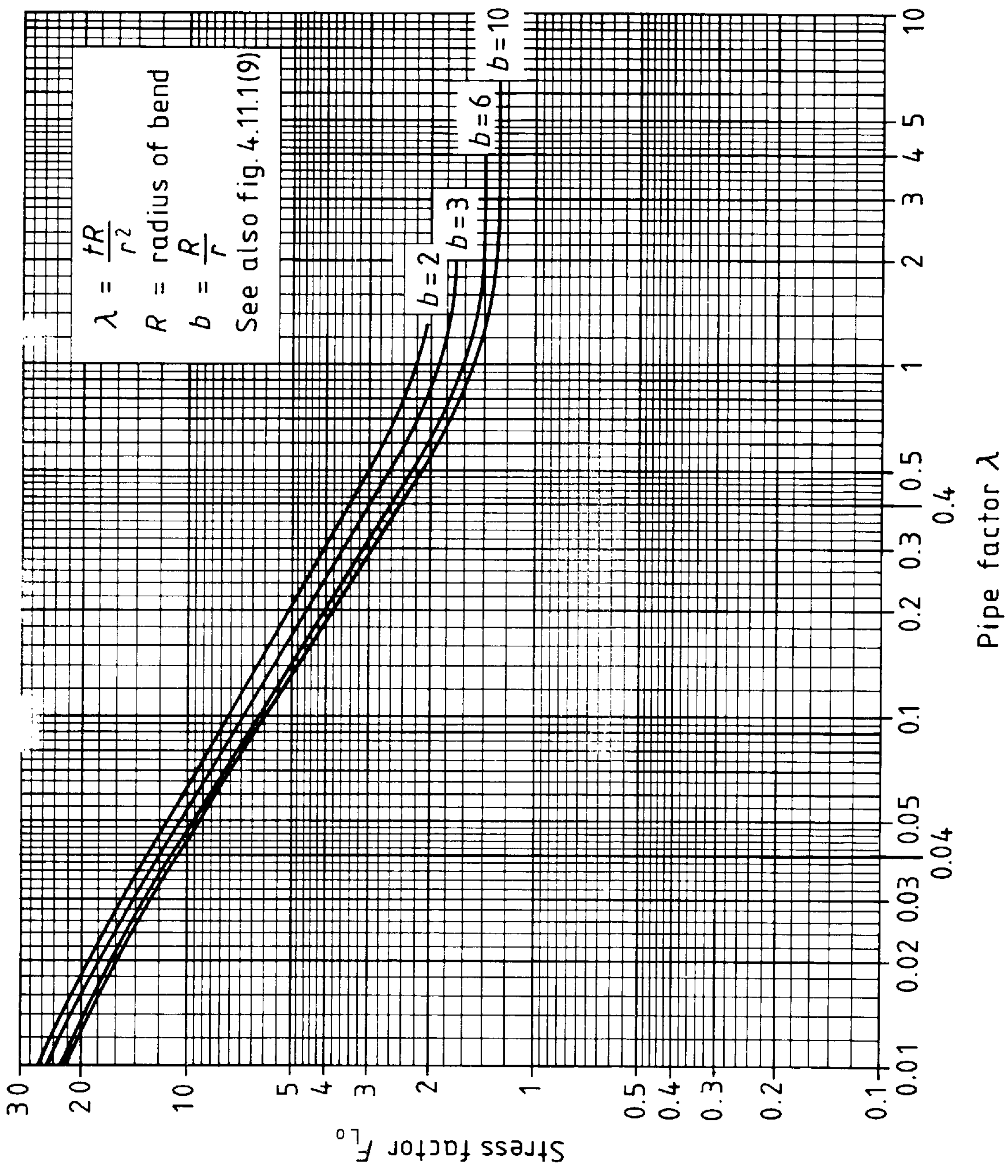


Figure 4.11.1(4) Maximum out-of-plane longitudinal stress factor (bends)

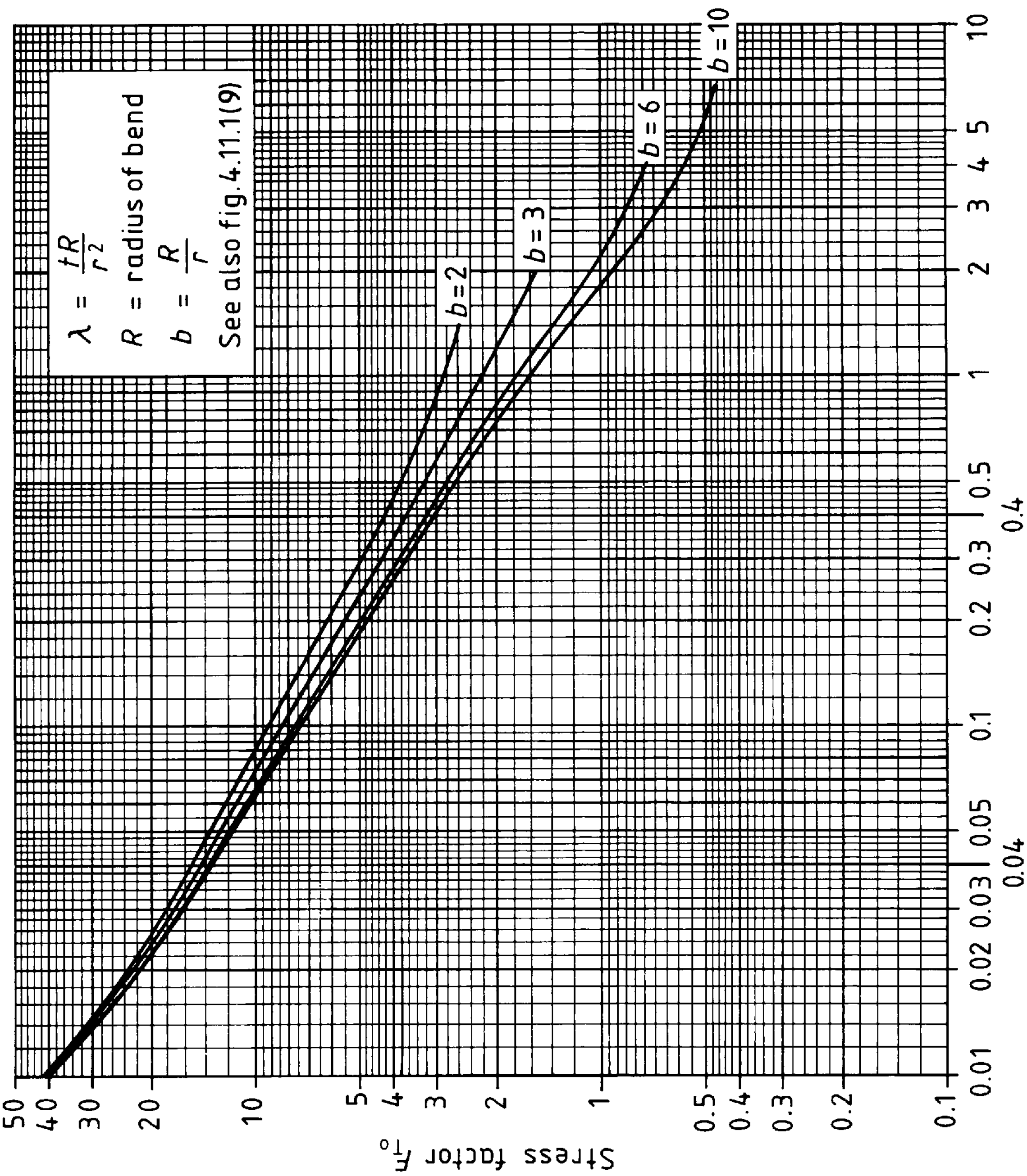
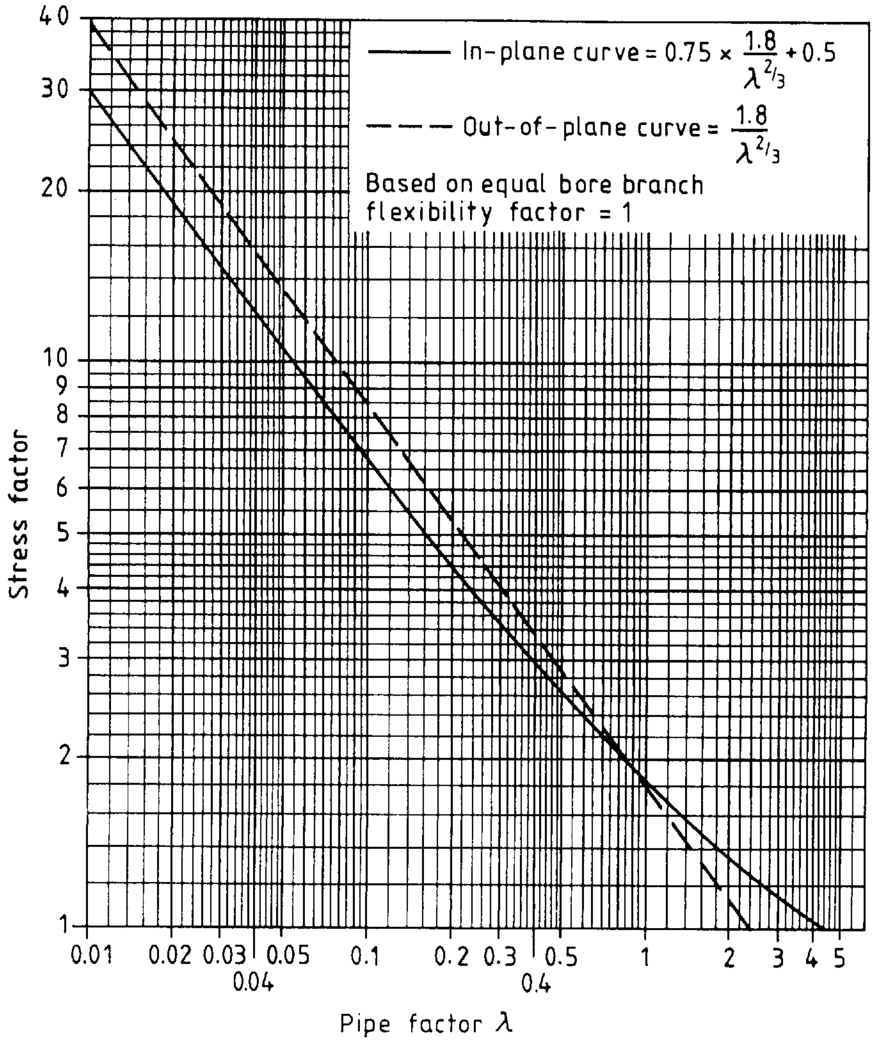
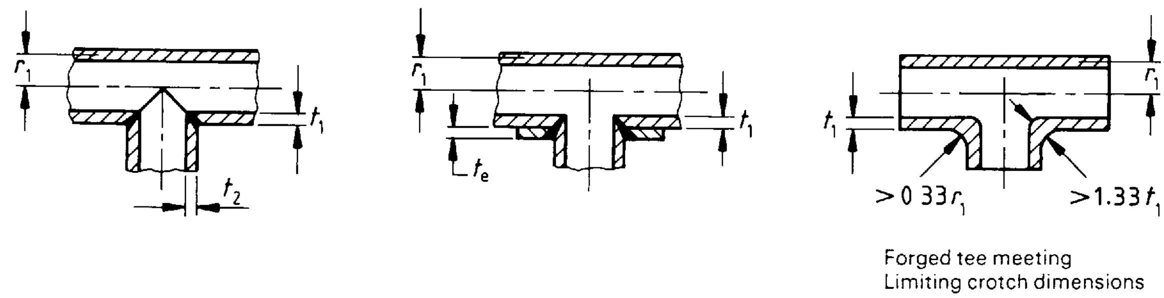


Figure 4.11.1(5) Maximum out-of-plane transverse stress factor (bends)





$$\lambda = \frac{t_1}{r_1}\left(1 + \frac{t_2}{r_1}\right)$$

(a)

$$\lambda = \frac{(t_1 + \frac{1}{2} t_e)^{5/2}}{(t_1)^{3/2} r_1}$$

(b)

$$\lambda = 4.4 \frac{t_1}{r_1}$$

(c)

Figure 4.11.1(6) Maximum non-directional stress factors (branches)

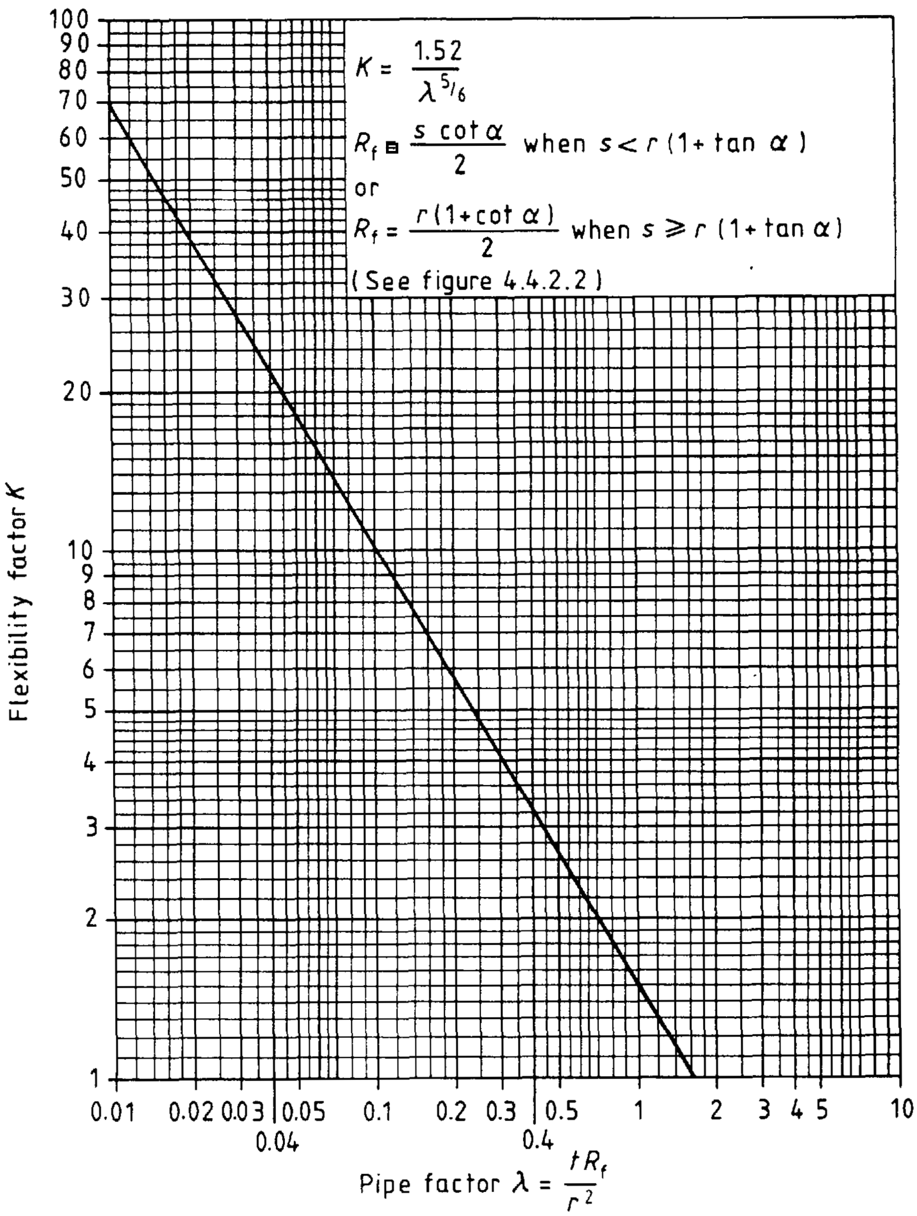
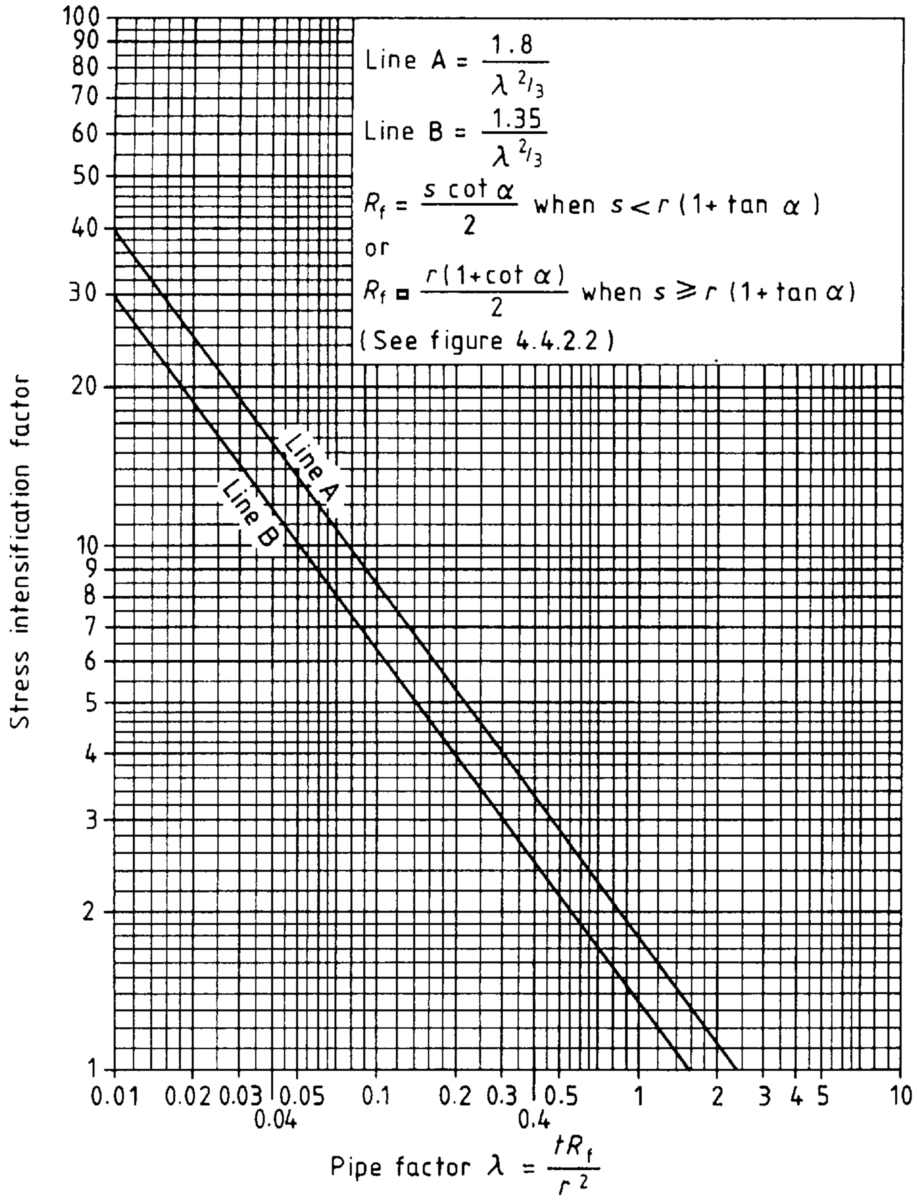


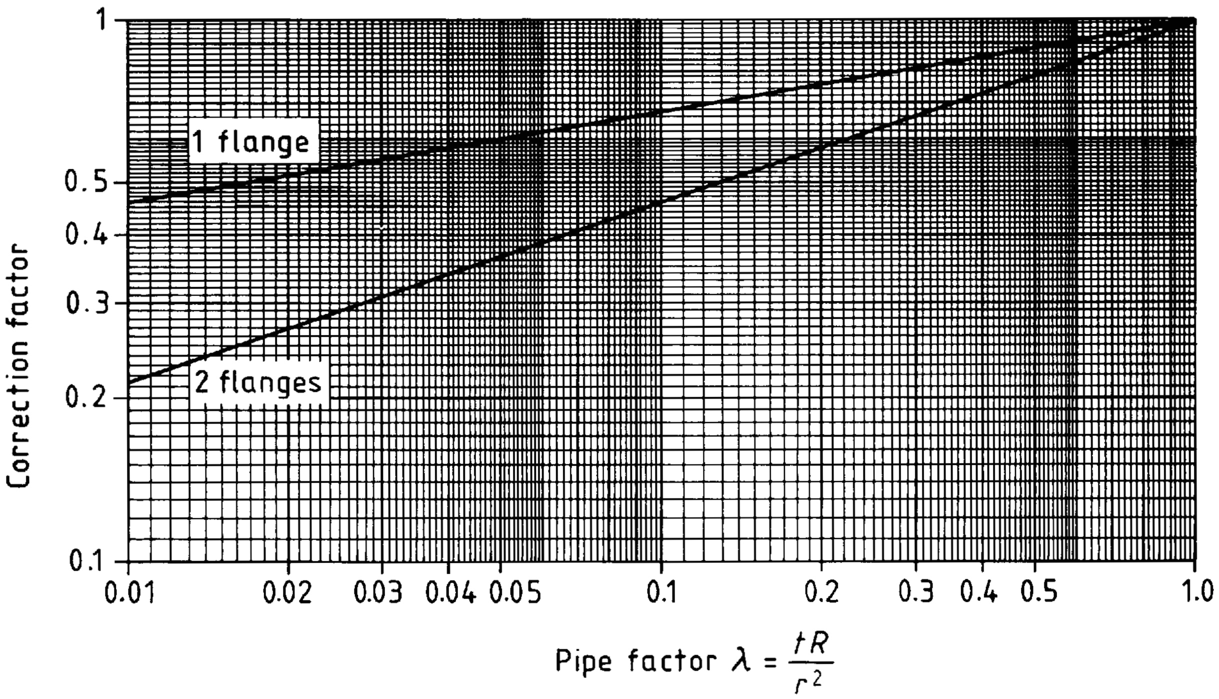
Figure 4.11.1(7) In-plane and out-of-plane flexibility factor, *K*, for multi-mitred bends



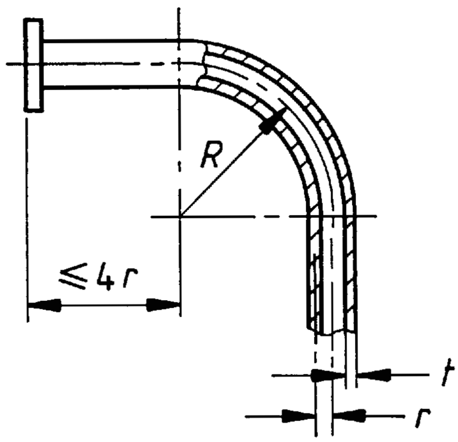
Line A: transverse stress intensification factor for in-plane and out-of-plane, F_{Ti} and F_{To}.

Line B: longitudinal stress intensification factor for in-plane and out-of-plane, F_{Li} and F_{Lo}.

Figure 4.11.1(8) Stress intensification factors for mitred bends



Only applicable where flange is within 4*r* of tangent.



NOTE. For one flange the correction factor is $\lambda^{1/6}$; for two flanges the correction factor is $\lambda^{1/3}$.

Figure 4.11.1(9) Stress intensification and flexibility correction factor for flanged bends

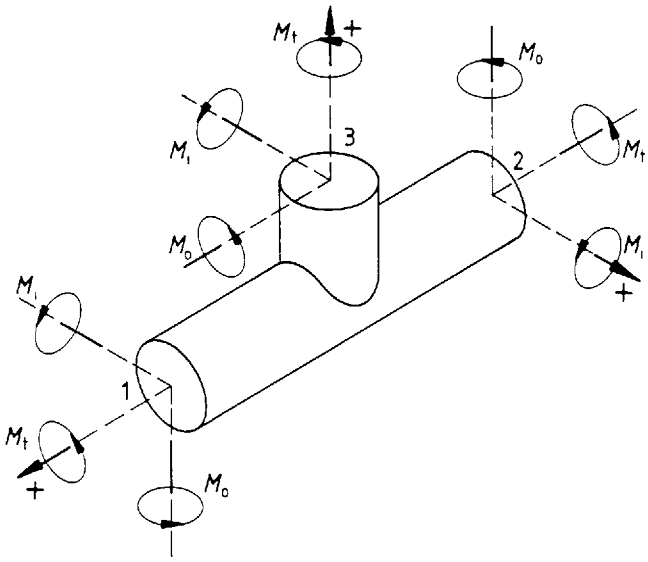


Figure 4.11.5.1 Branch connections

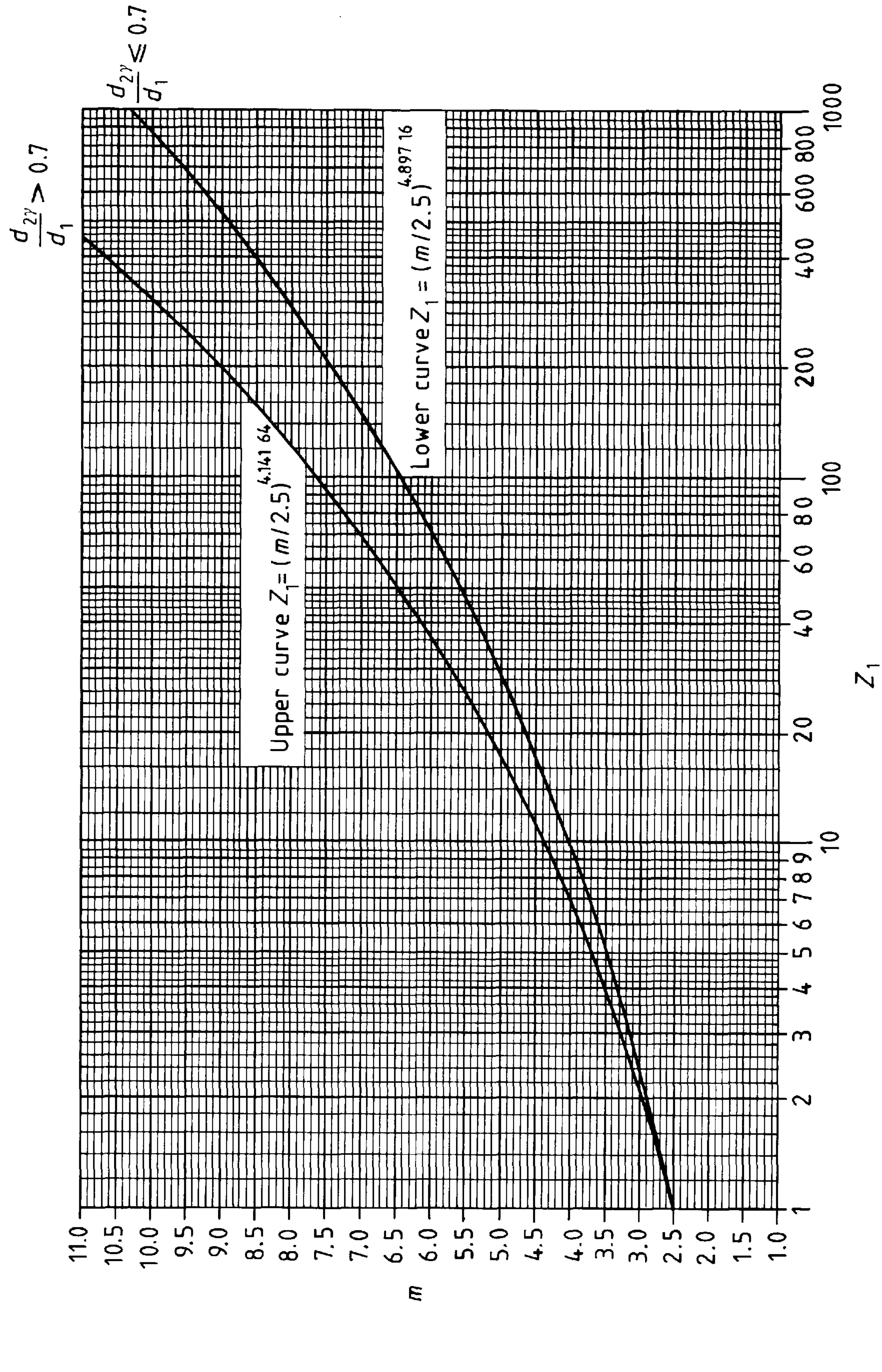


Figure 4.11.5.2 Pressure/stress multiplier

Section five. Construction and workmanship

5.1 General

Contamination of the surfaces of the pipes by corrosive or other detrimental substances, particularly by non-ferrous metals and sulphur, shall be avoided; e.g. during heating, adequate measures shall be taken to prevent sulphur pick-up. Filling sand, if used, shall be inert and no paint, labels or tools containing lead, copper, zinc or tin shall be used.

Contamination of austenitic steels by ferritic steels shall be avoided.

It is essential that alloy steel pipes, when cold, shall not be subjected to impact or hammer blows likely to cause local damage. Every precaution shall be taken to avoid such occurrences in handling and during all operations on the pipes. Care shall be taken in fabrication and manipulation to avoid the formation of notches or other sharp changes of contour likely to cause stress concentration.

5.2 Heat treatment and final condition

5.2.1 Final heat treated condition of pipes

Before erection as part of a pipework installation, all pipes, whether straight or manipulated, shall be in the heat treated condition given in table 5.2.1. Where there is subsequent welding, the heat treatment of the welds shall comply with **5.3**.

5.2.2 Cold forming

Pipes of the materials given in table 5.2.1 that have been cold formed shall be supplied in the following condition:

(a) when cold bent to a radius less than 3.5*D* (see **1.3.2**), they shall be heat treated in accordance with table 5.2.1;

(b) when cold bent to a radius of 3.5*D* or greater and they have been heat treated as specified in the materials specification before bending, no reheat treatment is required after bending.

5.2.3 Hot forming: ferritic steels

Hot forming of ferritic steels shall be carried out after heating in the range 850 °C to 1100 °C. Following hot forming, pipes shall be treated as given in table 5.2.1. If the pipe has been heated to normalizing temperature and the hot forming operation completed above 750 °C, subsequent normalizing is not required for carbon and carbon manganese steels, excluding 500 Nb.

NOTE. Attention is drawn to the possibility of hydrogen cracking in steel 762 if heat treatment is delayed following hot working.

5.2.4 Hot forming: austenitic steels

Hot forming of austenitic steels shall be carried out after heating in the range 900 °C to 1100 °C. If the pipe has been heated to the solution treatment temperature, the hot forming operation completed at a temperature exceeding 900 °C, and rapid cooling in air or water has

Table 5.2.1 Heat treatment of completed pipes

Figures in parentheses refer to the notes following this table.

Material	Grade	Heat treatment temperature		
		Normalized	Tempered	Solution treated
		°C	°C	°C
C C Mn		880 to 940 (1)	–	–
C Mn Nb	500 Nb	850 to 960	–	–
1 Cr 1/2 Mo	620-440	900 to 960	640 to 720	–
1 1/4 Cr 1/2 Mo	621	900 to 960	640 to 720	–
1/2 Cr 1/2 Mo 1/4 V	660	930 to 980	680 to 720	–
2 1/4 Cr 1 Mo	622	900 to 960	680 to 750	–
12 Cr Mo V	762	1020 to 1070	730 to 780	–
15 Cr 10 Ni 6 Mn Nb V	215 S15	–	–	1050 to 1150
18 Cr 10 Ni	304	–	–	1000 to 1100
18 Cr 12 Ni Mo	316	–	–	1000 to 1100
18 Cr 12 Ni Ti	321 S31	–	–	1000 to 1100
	S51 (1010)	–	–	950 to 1070
18 Cr 12 Ni Ti	321 S51 (1105)	–	–	1070 to 1140
18 Cr 12 Ni Nb	347	–	–	1000 to 1100
1 1/4 Ni Cu Mo Nb	591	900 to 980 (2)	580 to 660 (2)	–

NOTE 1. As an alternative to normalizing, except where precluded by **5.2.2** and **5.2.3**, carbon and carbon manganese steel pipes may be in the hot finished, subcritically annealed, or as welded condition permitted by the material specification.

NOTE 2. This steel may also be quenched from the range 880 °C to 930 °C, followed by tempering in the range 620 °C to 690 °C.

been carried out, subsequent solution heat treatment is not required for 304, 316, 321 and 347 grades listed in table 5.2.1, except for grade 321S51 (1105), which shall be solution heat treated as specified after hot bending.

NOTE. In order to ensure uniform soaking, the temperature for normalizing should be maintained for a time proportionate to the thickness of the pipe at a rate of not less than 1.2 min/mm of maximum thickness, followed by cooling in still air.

5.2.5 Local adjustment of components

As a result of fabrication operations during the manufacture of tubular assemblies and integral piping, distortion or deformation may occur due to welding shrinkage or inaccuracy in bending operations. The adjustment of such components to acceptable dimensional tolerances using local heating is permitted, provided that due recognition is given to the final supply condition of the component.

5.3 Welding

5.3.1 General

Welds shall be either:

(a) in accordance with BS 1821, BS 2633, BS 2640, BS 2971, BS 4204 and BS 4677; or

(b) by agreement between the purchaser and the manufacturer, in accordance with processes, other than those covered by the standards specified in (a), that have been demonstrated as being suitable (see **1.4.2.3**(e)).

5.3.2 Dressing of welds

Any dressing of welds within the provisions of the standards listed in **5.3.1** shall be such that the thickness remaining is not less than the minimum required by this standard.

5.3.3 Use of class I and class II welding for ferritic materials

5.3.3.1 Class I welding shall be used for steam services exceeding 17 bar or 220 °C, except that for a design temperature T (in °C), over 220 °C up to and including 400 °C, it is permissible to use class II welding provided all the following conditions are satisfied.

(a) The design pressure (in bar) shall not be greater than:

$$17\left(\frac{400 - T}{180}\right)$$

(b) The pipework shall be of carbon steel having a carbon content not exceeding 0.25 % (m/m) *.

(c) The actual thickness of the pipe at the butt weld shall be not less than twice the calculated design thickness.

(d) The pipework shall be tested in either of the following ways:

(1) the entire circumference of all butt welds shall be non-destructively tested by an ultrasonic or radiographic method; or

(2) the pipework shall be hydraulically tested in accordance with **6.2.1** and the entire circumference of 10 % of the butt welds made by each welder, selected at random, shall be subjected to non-destructive testing by an ultrasonic or radiographic method.

5.3.3.2 Class I welding shall be used for feed services exceeding 24 bar or 200 °C.

5.3.3.3 The use of class II welding is permitted for steam and feed services whose design conditions do not exceed the relevant limits specified in **5.3.3.1** and **5.3.3.2**.

NOTE. The requirements of **5.3.3** are shown in schematic form in figure 5.3.3.

5.3.4 Matching of pipe bores and outside diameters for butt welding

When possible, pipe matching problems caused by tube manufacturing tolerances, e.g. ovality, eccentricity, shall be overcome by selection, drifting, machining, swaging, or by the use of a suitable expander. When it is not possible to use any of these methods, the bore, or outside diameter of the end of the pipe shall be built up by welding. The weld build-up shall be done only under the following conditions.

(a) The thickness of the pipes to be joined shall meet the minimum design requirements of section four.

(b) The deposited weld metal shall have mechanical properties at least equal to those of the butt weld at the design temperature.

(c) Welding shall be done to the requirements of an approved welding procedure.

(d) Every built-up pipe end, regardless of size, shall be subject to 100 % non-destructive examination, using the same methods as those specified for the butt weld (see tables 6.3.3 and 6.3.4).

(e) The length of the pipe build-up shall be a minimum of 25 mm. Where ultrasonic examination of the butt weld is to be done, the length of the build-up shall be suitable to allow full ultrasonic coverage of the weld.

5.4 Attachment of branches

Branches, bosses and drain pockets shall be welded to the pipes and the welding shall comply with **5.3**.

Minimum dimensions for external profiles of class I welds at branches shall be as given in figure 5.4.

5.5 Attachment to flanges (see figures 5.5(1) to 5.5(9))

5.5.1 General

Flanges shall be secured to the pipes by welding or by screwing.

* Percentage by mass.

5.5.2 Welded-on flanges

5.5.2.1 Where flanges are welded on, the processes used shall be in accordance with **5.3.1**.

Oxy-acetylene welding is permitted only for type 1 flanges (see figure 5.5(1)) of carbon steel or 1 % Cr ½ % Mo steel or type 7 flanges (see figure 5.5(9)).

The preparation of the welds shall be as shown in figures 5.5(1) to 5.5(9).

Flanges shall not be tight fit on the pipe. The maximum clearance between the bore of the flange and the outside diameter of the pipe shall be as given in table 5.5.2.1.

Table 5.5.2.1 Maximum clearance between pipes and flanges

Nominal thickness of pipe	Maximum clearance between bore of flange and outside diameter of pipe	Sum of the diametrically opposite clearances, maximum	Weld leg length, minimum
mm	mm	mm	mm
Over 5	3	5	6
Over 4 up to and including 5	2.5	4	5
Over 3 up to and including 4	2	3	4
Up to and including 3	1.5	2	3

5.5.2.2 The limiting design conditions for each type of flange shall be as given in table 5.5.2.2.

Table 5.5.2.2 Limiting design conditions for flange types
Figures in parentheses refer to the notes following this table.

Flange type	Limiting flange type			Maximum temperature	Maximum pipe outside diameter	Minimum pipe bore
	BS 10(1)	BS 1560: Section 3.1	BS 4504: Section 3.1			
	Table	Class/Code	Designation/Code	°C	mm	mm
1	No restriction	No restriction	PN 40/111	No restriction	No restriction	No restriction
2	No restriction	Not applicable	PN 40/101	No restriction	168.3 for alloy and 500 Nb steels(2)	No restriction
3, 3A (3)	No restriction	Not applicable	PN 40/101	No restriction	168.3 for alloy and 500 Nb steels(2)	75
4	R	Not applicable	PN 40/101	425	No restriction	No restriction
4A		900/112	PN 40/112			
5, 5A (3)	R	Not applicable	PN 40/101	425	No restriction	75
6	J	Not applicable	PN 40/101	425	No restriction	No restriction
6A		300/112	PN 40/112			
7	H	300/112	PN 40/112	400	168.3	No restriction

NOTE 1. This British Standard is obsolescent.

NOTE 2. No restriction for carbon steels.

NOTE 3. Flange types 3, 3A and 5, 5A (BS 4504 : Section 3.1) require the flange to be supplied with a bore less than the outside diameter of the pipe.

5.5.3 Screwed-on flanges

Where flanges are secured by screwing, the screw thread shall comply with BS 21. The threads on the pipe and in the flange shall be arranged to end at a point just inside the back or boss of the flange. After the flange has been screwed on, the pipe shall be expanded into the flange by a roller expander. The use of such screwed and expanded flanges is permitted for steam for a maximum design pressure of 30 bar and a maximum design temperature of 370 °C, and for feed for a maximum design pressure of 50 bar.

5.6 Ovality of bent pipes

Ovality, calculated in accordance with equations (41) and (42), shall not exceed 5 % :

$$\text{Ovality (\%)} = \frac{(D_{max} - D_n)\,100}{D_n} \qquad (41)$$

$$\text{Ovality (\%)} = \frac{(D_n - D_{min})\,100}{D_n} \qquad (42)$$

where

D_{max} is the maximum outside diameter in the bent section (in mm);

D_{min} is the minimum outside diameter in the bent section (in mm);

D_n is the average outside diameter in the straight pipe (in mm).

5.7 Gusseted bends

Gusseted bends shall be fabricated in accordance with BS 1821, BS 2633, BS 2640, BS 2971 or BS 4677 according to the limits of pressure and temperature defined in **5.3.3** for class I and class II welding, but taking into account the overall limiting conditions of use given in **4.4.2** and **4.4.3**.

5.8 Condition of pipes (see also 1.4.1(f))

5.8.1 All parts of piping installations shall, as far as is practicable, be cleaned internally of rust and other foreign matter to comply with BS 7079 : Part A1 : 1989, Sa2, excepting that for (a) and (c) following, the internal cleaning shall comply with BS 7079 : Part A1 : 1989, Sa2½.

In the following cases scale, sand and other foreign matter shall be removed by pickling in inhibiting acid or by blasting with abrasive material:

(a) all alloy steel pipes;

(b) all carbon steel pipes where hot work has been carried out during fabrication for design pressures above 15 bar;

(c) all pipes within the feed and steam pipes systems where the boiler design pressure exceeds 64 bar.

After cleaning and before despatch, all pipe ends shall be fitted with suitably sealed protective end covers which shall be maintained in position until immediately before erection.

5.8.2 Immediately before erection, all parts of piping installations shall be checked for internal cleanliness.

5.9 Marking of pipes

Stamps shall be of the low stress type except that stamping on the body is not permitted for alloy steel.

NOTE. Inspection or identification marks may be stamped on the end faces of plain-end pipes or on the rims of flanges or on identification plates suitably attached to the pipes. Alternatively, inspection and identification marks may be vibro-etched or painted on the pipes provided iron oxide base or titanium base paints are used (see **5.1**).

5.10 Erection of pipework

5.10.1 General

Cold pull procedure shall be such as to ensure that correct angulation and rotation are imposed; for this purpose alignment marks shall be made at the cold gaps. Pipe ends at gaps shall be parallel with each other before pulling together.

Where the final joint is made by butt welding and is to be post-heat treated, the forces required to position the pipes shall be maintained by external means until completion of the heat treatment procedure.

The pipes to be pulled shall be hanging freely when the gap is measured, i.e. there should be no out-of-balance spring effort or any intermediate restraints other than those necessary to counteract any horizontal components of out-of-vertical supports. This condition shall also apply when alignment marks and end checks are made.

After the pipes have been pulled together, alignment shall be strictly maintained.

NOTE. Consideration should be given, where necessary, to the provision of temporary supports to reduce the deadweight stress due to the additional weight of test water.

5.10.2 Balanced erection

Where terminal forces and moments acting upon plant have to be maintained within close limits a site erection procedure shall be prepared and executed in a manner to demonstrate that the principles of design are achieved.

The detailed procedure shall set out the step by step method of erection for the particular installation (see **4.11.1**).

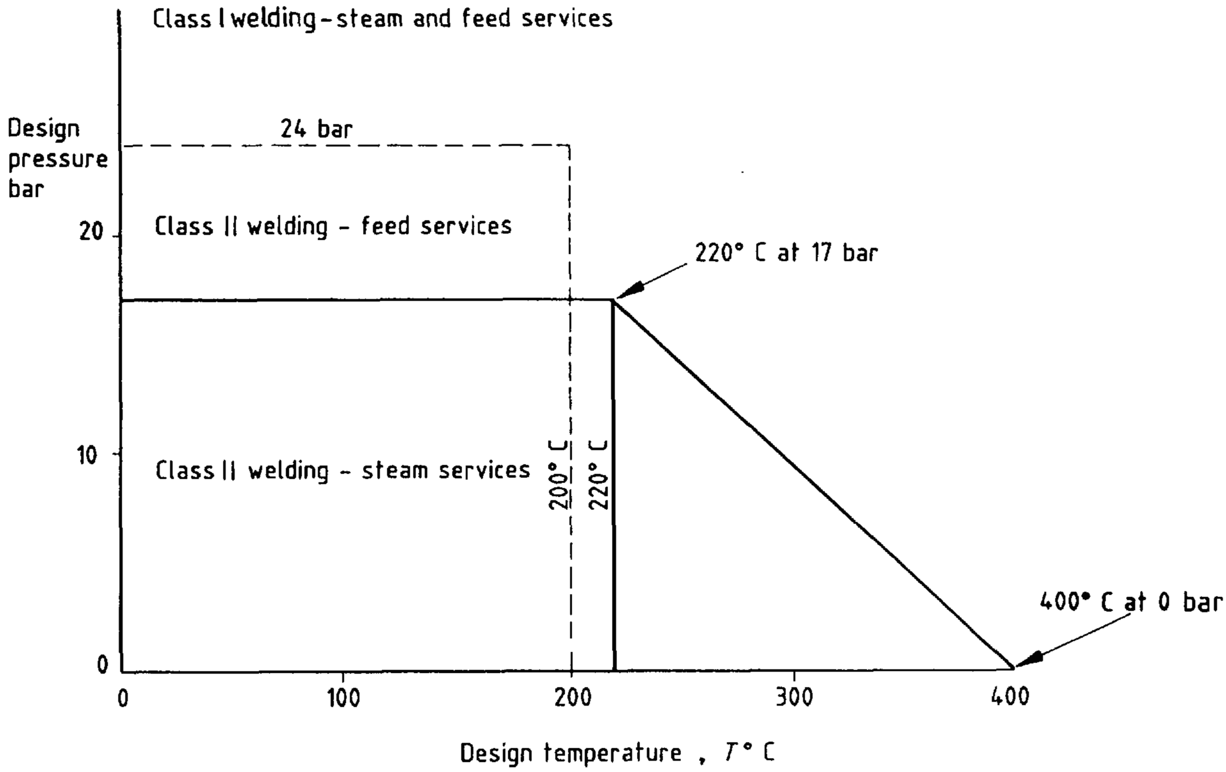
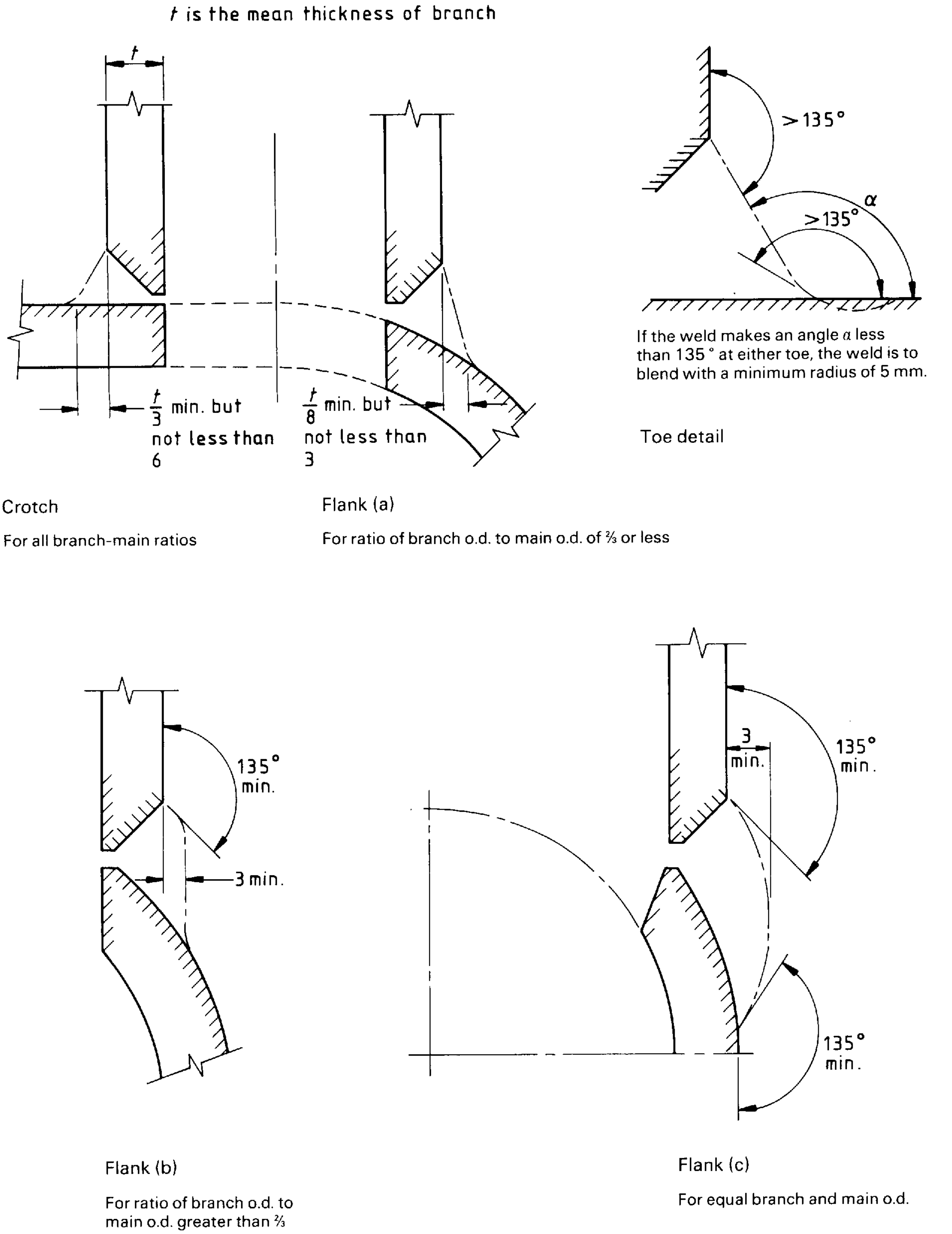


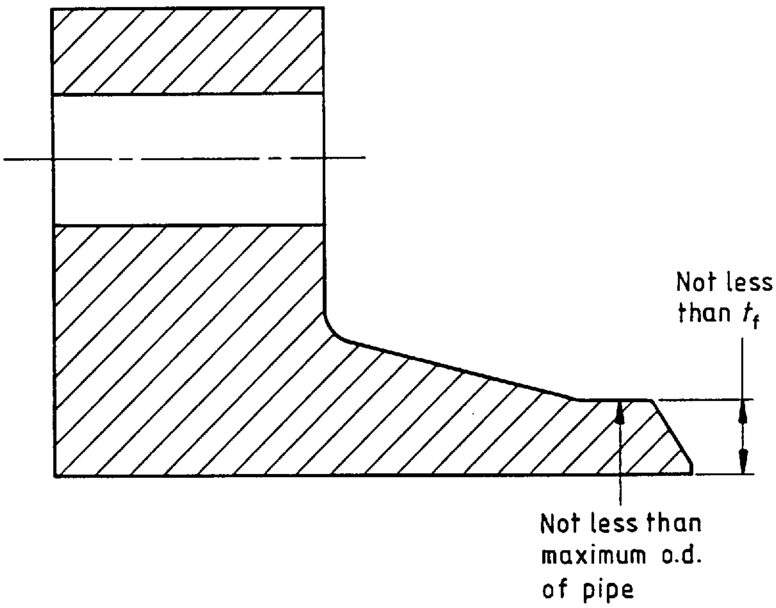
Figure 5.3.3 Use of class I and class II welding for ferritic materials



NOTE 1. All linear dimensions are in millimetres.

NOTE 2. The weld preparation in the shaded areas needs to be determined by the weld process and the appropriate welding standard.

Figure 5.4 Minimum dimensions for external profiles of welds at branches: class I welding

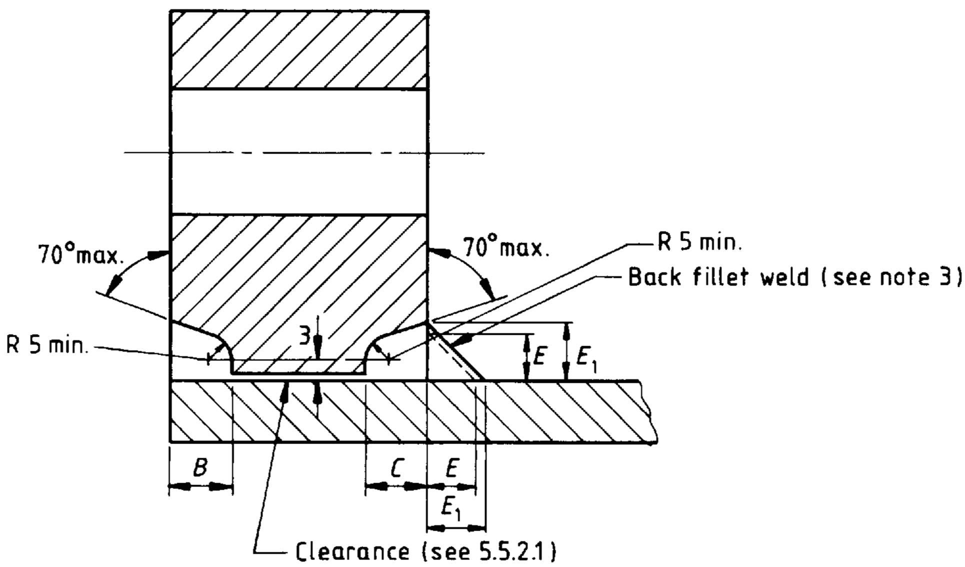


NOTE 1. Preparation and assembly for welding to be in accordance with **5.3**.

NOTE 2. t_f is the calculated pipe thickness (see **4.2**).

NOTE 3. This type of attachment is suitable for the design conditions given in table 5.5.2.2.

Figure 5.5(1) Type 1 'welding neck' flange



All linear dimensions are in millimetres.

Dimension	Steel	Design basis	
B	Carbon	t_f	but not less than 5
	Alloy and 500 Nb	$2t_f$	
C	Carbon	t_f	but not less than: 6 for pipes 15 and 20 nominal size 8 for pipes 25 to 40 nominal size 10 for pipes 50 nominal size and over
	Alloy and 500 Nb	$2t_f$	
E	Carbon	t_f but not less than 6	
E_1	Alloy and 500 Nb	Height of weld recess	

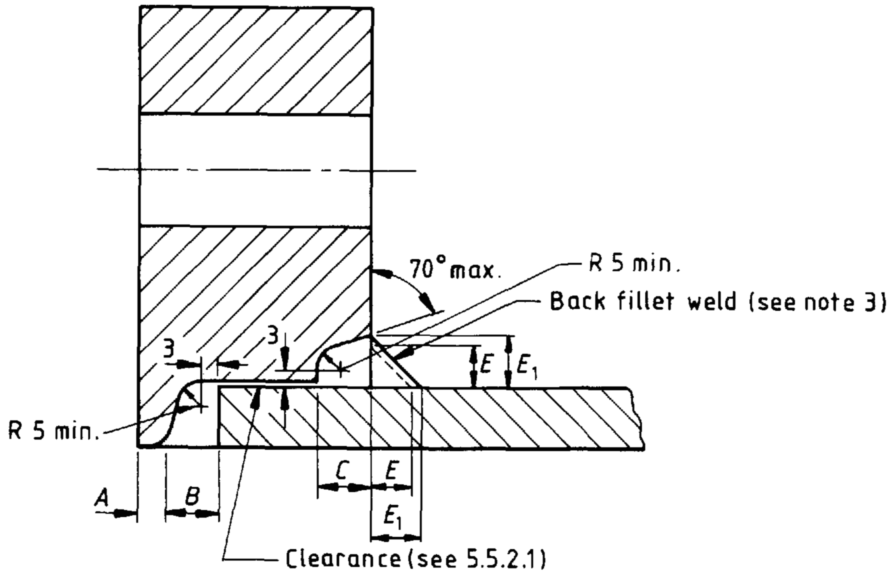
NOTE 1. Dimensions *B* and *C* are minima after machining the flange to final thickness.

NOTE 2. t_f is the calculated pipe thickness (see **4.2**).

NOTE 3. The outer surface of the weld needs to lie wholly outside the position indicated by the dotted line or full line, whichever is applicable.

NOTE 4. This type of attachment is suitable for the design conditions given in table 5.5.2.2.

Figure 5.5(2) Type 2 'face and back' welded-on flange (for metal-arc welding)



All linear dimensions are in millimetres.

Dimension	Steel	Design basis	
A	Carbon, alloy and 500 Nb	$\frac{1}{2}\, t_f$ but not less than 5	
B	Carbon, alloy and 500 Nb	8 minimum $(t_f - 1.5)$ where t_f is over 9.5 up to and including 14 $(t_f - 3)$ where t_f is over 14 up to and including 22 $(t_f - 6)$ where t_f is over 22	
C	Carbon	t_f	but not less than 10
	Alloy and 500 Nb	$2t_f$	
E	Carbon	t_f but not less than 6	
E_1	Alloy and 500 Nb	Height of weld recess	

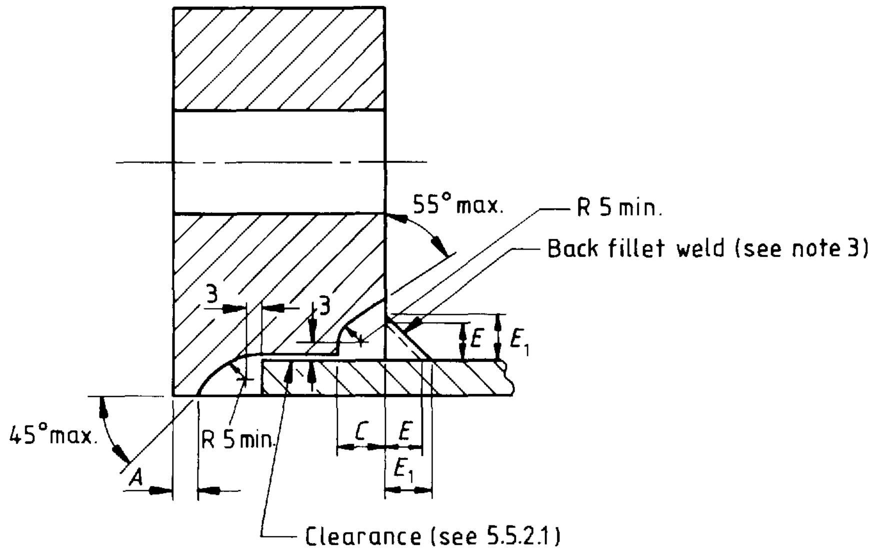
NOTE 1. Dimensions A and C are minima after machining the flange to final thickness.

NOTE 2. t_f is the calculated pipe thickness (see **4.2**).

NOTE 3. The outer surface of the weld needs to lie wholly outside the position indicated by the dotted line or full line, whichever is applicable.

NOTE 4. This type of attachment is suitable for the design conditions given in table 5.5.2.2.

Figure 5.5(3) Type 3 'bore and back' welded-on flange (for metal-arc welding)



All linear dimensions are in millimetres.

Dimension	Steel	Design basis	
A	Carbon, alloy and 500 Nb	$\frac{1}{2} t_f$ but not less than 5	
C	Carbon	t_f	but not less than 10
	Alloy and 500 Nb	$2t_f$	
E	Carbon	t_f but not less than 6	
E_1	Alloy and 500 Nb	$\frac{2}{3} t_f + 6$ but not less than t_f	

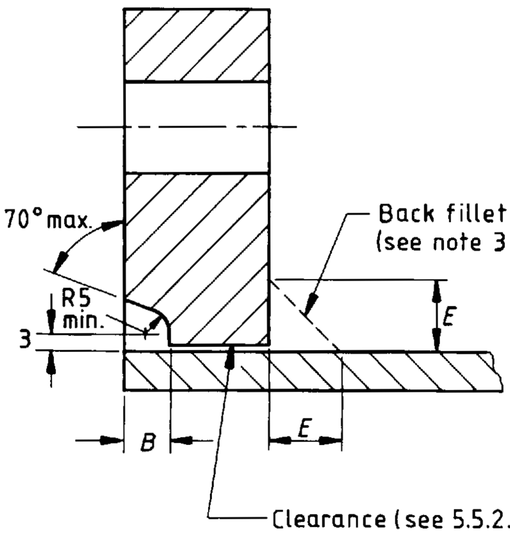
NOTE 1. Dimensions A and C are minima after machining the flange to final thickness.

NOTE 2. t_f is the calculated pipe thickness (see **4.2**).

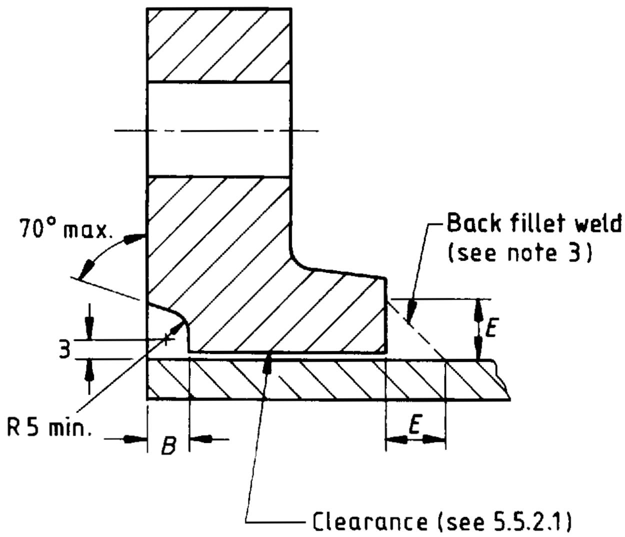
NOTE 3. The outer surface of the weld needs to lie wholly outside the position indicated by the dotted line or full line, whichever is applicable.

NOTE 4. This type of attachment is suitable for the design conditions given in table 5.5.2.2.

Figure 5.5(4) Type 3A 'bore and back' welded-on flange (weld preparation for use only with flanges positionally welded on by the metal-arc process)



(a) Type 4 flange



(b) Type 4A flange

All linear dimensions are in millimetres.

Dimension	Design basis
B	t_f but not less than the weld leg length given in table 5.5.2.1
E	1½ t_f but not less than the weld leg length given in table 5.5.2.1

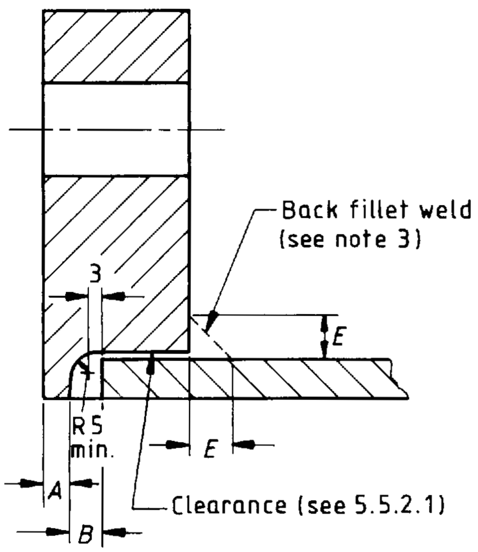
NOTE 1. Dimension *B* is the minimum after machining the flange to final thickness.

NOTE 2. t_f is the calculated pipe thickness (see **4.2**).

NOTE 3. The outer surface of the weld needs to lie wholly outside the position indicated by the dotted line.

NOTE 4. This type of attachment is suitable for the design conditions given in table 5.5.2.2.

Figure 5.5(5) Types 4 and 4A 'face and fillet' welded-on flanges (for metal-arc welding)



All linear dimensions are in millimetres.

Dimension	Design basis
A	½ t_f but not less than 5
B	8 minimum (t_f − 1.5) where t_f is over 9.5 up to and including 14 (t_f − 3) where t_f is over 14 up to and including 22 (t_f − 6) where t_f is over 22
E	1½ t_f but not less than the weld leg length given in table 5.5.2.1

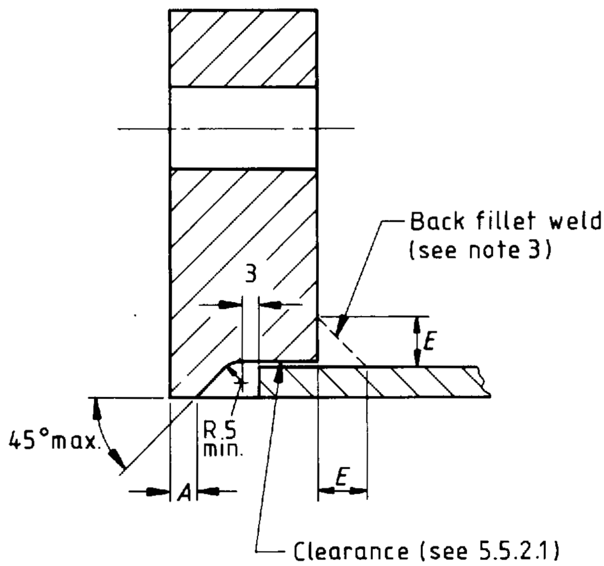
NOTE 1. Dimension *A* is the minimum after machining the flange to final thickness.

NOTE 2. t_f is the calculated pipe thickness (see **4.2**).

NOTE 3. The outer surface of the weld needs to lie wholly outside the position indicated by the dotted line.

NOTE 4. This type of attachment is suitable for the design conditions given in table 5.5.2.2.

Figure 5.5(6) Type 5 'bore and fillet' welded-on flange (for metal-arc welding)



All linear dimensions are in millimetres.

Dimension	Design basis
A	½ t_f but not less than 5
E	1½ t_f but not less than the weld leg length given in table 5.5.2.1

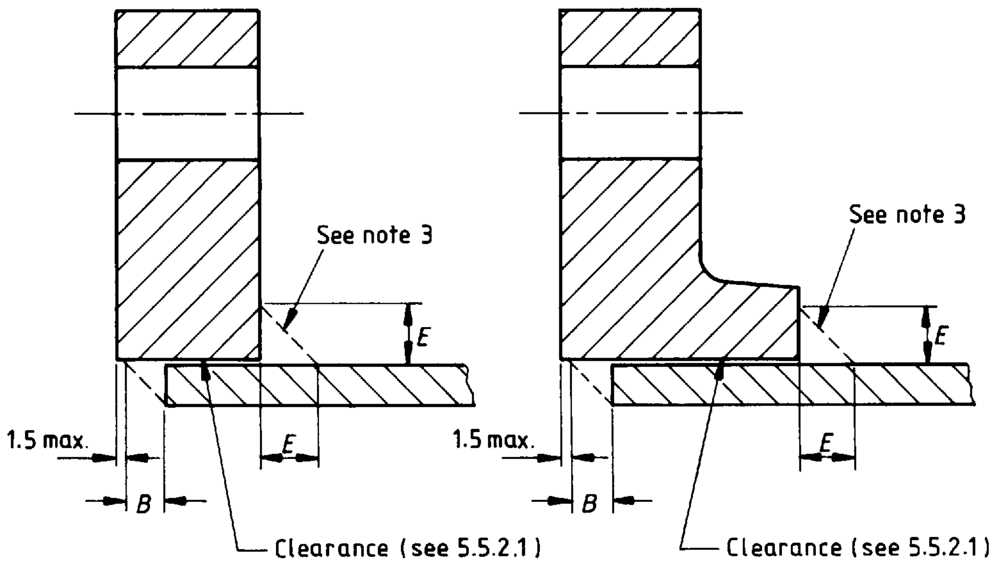
NOTE 1. Dimension *A* is the minimum after machining the flange to final thickness.

NOTE 2. t_f is the calculated pipe thickness (see **4.2**).

NOTE 3. The outer surface of the weld needs to lie wholly outside the position indicated by the dotted line.

NOTE 4. This type of attachment is suitable for the design conditions given in table 5.5.2.2.

Figure 5.5(7) Type 5A 'bore and fillet' welded-on flanges (weld preparation for use only with flange positionally welded on by the metal-arc process)



(a) Type 6 flange

(b) Type 6A flange

All linear dimensions are in millimetres.

Dimension	Design basis
B	t_f but not less than the weld leg length given in table 5.5.2.1
E	1½ t_f but not less than the weld leg length given in table 5.5.2.1

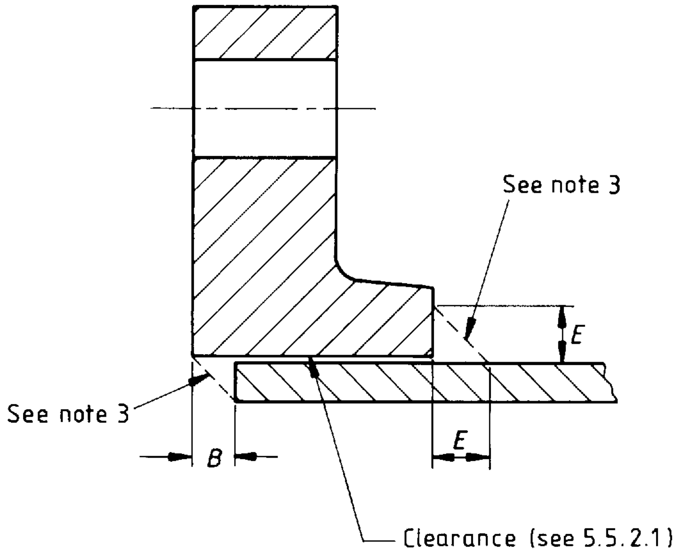
NOTE 1. All dimensions are finished sizes.

NOTE 2. t_f is the calculated pipe thickness (see **4.2**).

NOTE 3. The outer surface of the weld needs to lie wholly outside the position indicated by the dotted line.

NOTE 4. This type of attachment is suitable for the design conditions given in table 5.5.2.2.

Figure 5.5(8) Types 6 and 6A 'slip-on' welded-on flanges (for metal-arc welding)



Dimension	Design basis
B	t_f but not less than the weld leg length given in table 5.5.2.1
E	1½ t_f but not less than the weld leg length given in table 5.5.2.1

NOTE 1. All dimensions are finished sizes.

NOTE 2. t_f is the calculated pipe thickness (see **4.2**).

NOTE 3. The outer surface of the weld needs to lie wholly outside the position indicated by the dotted line.

NOTE 4. This type of attachment is suitable for the design conditions given in table 5.5.2.2.

Figure 5.5(9) Type 7 'slip-on' welded-on bossed flange (for oxy-acetylene welding)

Section six. Inspection and testing

6.1 Tests on pipes and fittings

6.1.1 Except as specified in **6.1.3**, completed wrought steel pipes and fittings shall be tested by hydraulic pressure.

Where hydraulic testing is required, compliance shall be demonstrated either by individual testing of components before erection or, alternatively (subject to the adequacy of the support system), a test of the pipe system after erection (see **6.2**). In the latter case it shall be possible to examine visually all parts of the components.

The test pressure P_t (in N/mm^2) shall be determined from equation (43) subject to a maximum pressure equal to 1.5p.

Table 6.1.1 Values of the specified minimum yield stress (R_e)			
Tube standard	**Steel grade**	**Thickness**	R_e
		mm	N/mm^2
BS 3601	320		195
	360	≤ 16 >16 ≤ 40 >40 ≤ 65	235 225 215
	430	≤ 16 >16 ≤ 40 >40 ≤ 65	275 265 255
BS 3602: Part 1	360	≤ 16 >16 ≤ 40 >40 ≤ 65	235 225 215
	430	≤ 16 >16 ≤ 40 >40 ≤ 65	275 265 255
	500 Nb	≤ 16 >16 ≤ 40 >40 ≤ 65	355 345 335
BS 3602: Part 2	430	≤ 16 >16 ≤ 40	250 240
	490	≤ 16 >16 ≤ 40	325 315
BS 3604: Part 1	591 620-440 621 660 622 762		440 290 275 300 275 470
BS 3604: Part 2	620 621 622		340 340 310
BS 3605: Part 1	304S11 S31, S51 316S11, S13 S31, S33, S51, S52 321S31, S51 (1010) S51 (1105) 347S31, S51 215S15		215 230 225 240 235 190 240 270

$$P_t = \frac{0.83 p R_e}{f} \qquad (43)$$

where

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

R_e is the specified minimum yield stress selected from table 6.1.1 (in N/mm^2);

f is the maximum permissible design stress (in N/mm^2) at the design temperature (see **3.2**).

The test pressure for a forged and/or cast pipe or fitting shall be that for equivalent wrought steel pipe for the same design conditions.

NOTE. Water is normally used as the pressurizing agent. Where other liquids are used, additional precautions may be necessary depending on the nature of the liquid. Attention is drawn to the need to control the chloride content of test water in the case of austenitic stainless steel pipes. To avoid the risk of freezing it is recommended that the temperature of the water, if used, during the test should be not less than 7 °C.

6.1.2 Pipes and fittings with flanges of rating equivalent to or higher than PN 25 of BS 4504 shall be tested either fully assembled or in sections with blank flanges bolted on.

NOTE. Other pipes, if straight, may, unless otherwise arranged between the purchaser and the manufacturer, be tested between the heads of a hydraulic pipe testing machine.

Blowdown pipes and drain pipes shall be treated as steam pipes in accordance with section two.

6.1.3 Waiver of the hydraulic pressure test requirement specified in **6.1.1** shall be permitted when both (a) and (b) following are satisfied.

(a) Any of the following conditions apply:

(1) the pipes have been ultrasonically tested in accordance with the requirements of any of the following standards:

BS 3602 : Part 1 test category 1
BS 3604 : Part 1 test category 1
BS 3605 : Part 1 test category 1

(2) the pipes have been hydraulically tested at a test pressure equal to or greater than that determined from equation (43) in accordance with the requirements of any of the following standards:

BS 3601
BS 3602 : Part 1 test category 2
BS 3602 : Part 2
BS 3604 : Part 1 test category 2
BS 3604 : Part 2
BS 3605 : Part 1 test category 2

(3) the pipes have been eddy current tested in accordance with the requirements of any of the following standards and the test pressure determined from equation (43) does not exceed 140 bar:

BS 3601
BS 3602 : Part 1 test category 2
BS 3604 : Part 1 test category 2

(b) If the work of manipulation and fabrication has only involved one or more of the following:

(1) end preparation for welding;

(2) welding of minor attachments such as pressure and temperature tappings subject to internal pressure by agreement between the purchaser and the manufacturer (see **1.4.2.3**(f));

(3) butt welding where the butt welds have been non-destructively examined in accordance with **6.3**.

6.1.4 Drain vessels shall be hydraulically tested to 1.5 times the design pressure.

6.1.5 With the exception of unworked pipe as defined in **6.1.3**, the test pressure shall be maintained at the required pressure for a sufficient length of time to permit a visual examination to be made of all surfaces and joints, and the test pressure shall be sustained for the minimum times given in table 6.1.5 prior to visual inspection.

Table 6.1.5 Minimum duration for the hydraulic test

Outside diameter	Minimum duration of test	
	Pressure up to and including 7 N/mm²	Pressure above 7 N/mm²
mm	min	min
Up to and including 273	10	15
Greater than 273	20	25

6.2 Hydraulic tests on pipe systems after erection

6.2.1 A hydraulic test to a test pressure determined from equation (43), subject to a maximum pressure of 1.5p, where p is the design pressure, shall be applied to the pipe system after erection in the following cases.

(a) Class I butt welded or fully flanged systems where the requirements of **6.1.1** have not been complied with before erection.

(b) All class II butt welded systems (including systems in which some flanged joints are used).

NOTE. If agreed between the manufacturer and the purchaser (see **1.4.2.2** (e), it is permissible to omit the hydraulic test on the completed installation provided that the requirements of **6.1.1** have been satisfied before erection and non-destructive examination in accordance with **6.3.4** is carried out.

6.2.2 Where the system contains piping components of differing calculated test pressures then the lowest test pressure shall be applied.

Where there are connected components which are not covered by this standard, the manufacturer shall ascertain that such components are suitable for the application of this test pressure or, if they are not, that the components are isolated from the system under test.

6.2.3 Safety valve escape piping, including that which incorporates bellows expansion joints, shall not be subjected to a hydraulic test after erection. Where bellows expansion joints are fitted, supports, anchors and guides shall be designed in accordance with BS 6129 : Part 1.

6.3 Visual and non-destructive examination

6.3.1 Visual examination

All welds shall be visually examined in accordance with BS 1821, BS 2633, BS 2640, BS 2971 or BS 4677 as appropriate.

6.3.2 General requirements for non-destructive examination

6.3.2.1 *Procedures for non-destructive examination.* Non-destructive examination shall be carried out to written procedures provided by the manufacturer and in accordance with the following British Standard methods:

magnetic particle	BS 6072
penetrant	BS 6443
radiography (butt welds)	BS 2910
ultrasonic	BS 3923 : Part 1 (except where specific variance is indicated in the following sections)

Type and extent of examination shall be as specified in **6.3.3** and **6.3.4**.

Surface finish requirements of pressure containment welds to facilitate examination shall be as specified in **6.3.5**.

6.3.2.2 *Timing of non-destructive examination.* The non-destructive examination shall be carried out after any required final heat treatment except in the case of carbon, carbon manganese, grade 620 and grade 621 alloy steels where it is permissible to carry out the examination before heat treatment in the following cases:

(a) butt welds;

(b) branch, socket and attachment welds, subject to agreement between the manufacturer and the purchaser (see **1.4.2.3**(g)).

6.3.2.3 *Non-destructive examination personnel*

NOTE. The successful application of non-destructive examination depends on the knowledge and experience of the personnel responsible for producing the examination procedures and the technical competence and ability of the practitioner to carry out the procedural requirements and interpret results.

Unless otherwise agreed between the contracting parties, (see **1.4.2.3**(h)) the appropriate level and category of certification of personnel shall be in terms of those obtained from an agreed nationally accredited certification scheme, e.g. the Personnel Certification in Non-Destructive Testing (PCN) scheme.

6.3.3 Type and extent of non-destructive examination for ferritic class I and austenitic welds

Type and extent of non-destructive examination for ferritic class I and austenitic welds shall be as specified in table 6.3.3.

The acceptable limitations in faults revealed by non-destructive examination shall be as specified in BS 2633 and BS 4677.

Table 6.3.3 Type and extent of non-destructive examination for ferritic class I and austenitic welds

Material grade (2)	Butt welds and welds attaching branches (5)		Socket welds	
	Pipe thickness <25 mm and outside diameter <170 mm (7) (8)	Pipe thickness ≥25 mm or outside diameter ≥170mm	Design temperature ≤400 °C	Design temperature >400 °C
C, C Mn, 620 621, 622	10 % RAD or USE (3) 6) and 10 % MPI (6)	100 % RAD or USE (3) and 100 % MPI	10 % MPI (6)	100 % MPI
591	100 % RAD or USE (3) and 100 % MPI	100 % RAD or USE (3) and 100 % MPI	Not to be used for this material	
762	100 % RAD or USE (3) and 100 % MPI or DPI (3)	100 % RAD or USE (3) and 100 % MPI or DPI (3)	Not to be used for this material	
660(4)	100 % USE (4) and 100 % MPI	100 % USE (4) and 100 % MPI	Not to be used for this material	
Austenitic steels	10 % RAD (6) and 10 % DPI (6)	100 % RAD and 100 % DPI	10 % DPI (6)	100 % DPI

NOTE 1. Notation
RAD = Radiography
USE = Ultrasonic examination
MPI = Magnetic particle inspection
DPI = Dye penetrant inspection

NOTE 2. Where dissimilar grades of metals are joined together, the extent of non-destructive examination shall be that of the higher grade.

NOTE 3. For materials where the method of non-destructive examination is optional and the purchaser has not specified one of the options, the manufacturer may choose the method to be adopted.

NOTE 4. For material grade 660, where the geometric shape of the connecting pipes partially or fully restricts the ultrasonic examination of the joint, radiographic examination may be used in the affected areas.

The examination is considered restricted when the full weld volume, including fusion faces, heat-affected zones and root areas, cannot be fully covered by both normal and angle beams due to limited access for scanning or lack of acoustic contact on the relevant scanning surfaces.

NOTE 5. All attachment welds other than branch welds shall be examined by the surface flaw detection technique and extent specified for the grade of material and dimensions of the pipe to which the attachment is welded.

NOTE 6. Percentage non-destructive examination entails examination of a percentage of the number of joints per process per welder. The joints selected for non-destructive examination shall be subjected to the appropriate volumetric and surface examinations.

NOTE 7. Due to restricted access on branches of 50 mm bore and below, radiography may be waived.

NOTE 8. BS 3923 : Part 1 is not applicable to pipes of wall thickness less than 6 mm or outside diameter less than 100 mm. Where BS 3923 : Part 1 does not apply, then radiography may be substituted.

When random radiographic or ultrasonic examination reveals unacceptable defects in a weld, at least two further welds in the group represented by this weld shall be examined by the same method. If the examination of these further welds in the group reveals no unacceptable defects, the defects in the first weld shall be repaired and re-examined by the original method. If the repair is satisfactory, the group of welds shall be accepted. If examination of either of the further welds in the group reveals unacceptable defects, each weld in the group shall be examined by the same method over its complete circumference. Unacceptable defects shall be repaired and then re-examined by the original method.

Where examination specified in table 6.3.3 reveals faults which are not within the limitations for class I welds, the faults shall be removed and the exposed part of the junction rewelded as necessary and re-examined.

6.3.4 Type and extent of non-destructive examination for carbon steel class II welds

Type and extent of non-destructive examination for carbon steel class II welds other than for butt welds applied to steam services which are in the range 220 °C to 400 °C, shall be as specified in table 6.3.4 except where hydraulic testing in accordance with **6.2.1** has been carried out, in which case non-destructive examination is not required.

Type and extent of non-destructive examination for carbon steel class II butt welds applied to steam services in the range 220 °C to 400 °C shall be as specified in **5.3.3.1**(d).

The acceptable limitations in faults revealed by non-destructive examination shall be as specified in BS 2971.

When random radiographic or ultrasonic examination of all or part of a weld reveals unacceptable defects, one further weld in the group represented by this weld shall be tested to the same extent. If this further weld shows no unacceptable defects, the defects in the first weld shall be repaired and then re-examined by the original method. If the repair is satisfactory, the group of welds shall be accepted. If the further weld shows unacceptable defects, each weld in the group shall be tested by the same method and to the same extent. Unacceptable defects shall be repaired and then re-examined by the original method.

Where examination specified in table 6.3.4 reveals faults which are not within the limitations for class II welds, the faults shall be removed and the exposed part of the junction rewelded as necessary and re-examined.

Table 6.3.4 Type and extent of non-destructive examination for carbon steel class II welds

(Applicable where welds have not been hydraulically tested in accordance with **6.2.1**.)

Butt welds and welds attaching branches		Attachment welds
Outside diameter <170 mm (5)	**Outside diameter ≥170 mm** (4)	
10 % RAD or USE (2) (3)	100% RAD or USE (2)	10 % MPI (3)

NOTE 1. NOTATION

RAD = Radiography
USE = Ultrasonic examination
MPI = Magnetic particle inspection

NOTE 2. Choice between radiography and ultrasonics shall be at the discretion of the manufacturer.

Where neither method is feasible then the surface flaw detection technique specified for attachment welds shall be used.

NOTE 3. Percentage non-destructive examination entails the examination of a percentage of the number of joints per process per welder. The joints selected shall be subjected to the appropriate volumetric and surface examinations.

NOTE 4. For pipes where for manufacturing reasons the actual minimum thickness at the weld is greater than twice the thickness calculated by equations (4) and (5), the entire circumference of 10% of the butt welds and welds attaching branches of this thickness made by each welder, selected at random with a minimum of one weld per welder, shall be subjected to non-destructive examination by either radiographic or ultrasonic methods.

NOTE 5. All butt welds complying with BS 2971 in carbon steel steam vent pipes shall be subjected to non-destructive examination by either radiographic or ultrasonic methods over their entire circumference.

6.3.5 Surface finish requirements for pressure containment welds

6.3.5.1 *External finish.*

NOTE. The external finish of pressure containment welds made in accordance with the appropriate welding standard may inhibit the non-destructive examination of welds.

Where non-destructive examination is required, the weld external finish and/or surfaces adjacent to the weld over which angled ultrasonic probes are scanned shall be at least in accordance with the highest finish number given in table 6.3.5 for the combination of non-destructive examination procedures.

Table 6.3.5 Weld external surface finish

Material grade	Non-destructive examination procedure			
	Magnetic particle	Radiography	Ultrasonic	Dye penetrant
	Finish number	Finish number	Finish number	Finish number
C, C Mn 620, 621	SP1/SP6	SP1/SP6	SP1/SP6 (see note 1)	SP1/SP6
591, 622, 762	SP1/SP6	SP1/SP6	SP4/SP7	SP1/SP6
660	See note 2	See note 2	SP4/SP7	See note 2
Austenitic steels	Not applicable	SP1/SP6	Not applicable	SP1/SP6

NOTE 1. Finish SP4 shall be applied instead of SP1 where the pipe outside diameter geometry restricts the ultrasonic examination.

NOTE 2. Welds joining chromium molybdenum vanadium pipes shall be dressed to a smooth contour, blending weld and parent metal, and the reinforcement shall be ground smooth to ensure the removal of all surface fissures and undercut (see clause **21** of BS 2633 : 1987).

External finish categories are illustrated in figure 6.3.5.1, based on appendix B of BS 3923 : Part 1 : 1986 and are as follows.

(a) *Finishes SP1 and SP6.* No dressing shall be required except where necessary to remove the source of any confusing ultrasonic signals or surface features which may interfere with the interpretation of the weld when other non-destructive examination methods are employed.

(b) *Finish SP4.* The weld, and where necessary the adjacent parent material, shall be dressed to a sufficiently high standard to allow ultrasonic probes to be scanned smoothly over the surface while maintaining satisfactory and reproducible coupling. The conditions required for this are as follows.

(1) The maximum permitted deviation of the surface from its ideal shape is 1.5 mm in any 50 mm length of surface.

On flat or straight sections, this shall be assessed by measuring the maximum gap which can develop under a 50 mm long straight edge placed against the surface.

For butt welds connecting to welding elbows or other curved surfaces, the maximum permissible deviation in surface flatness is 1.5 mm in any 50 mm length over and above the normal radius of the curved surface. If acoustic contact is not attainable with the surface finish specified, then further dressing may be carried out providing the remaining thickness is equal to or greater than the minimum pipe thickness.

(2) For wall thicknesses up to and including 100 mm the centreline average, R_a, of surface finish from which ultrasonic scanning is to be carried out shall be

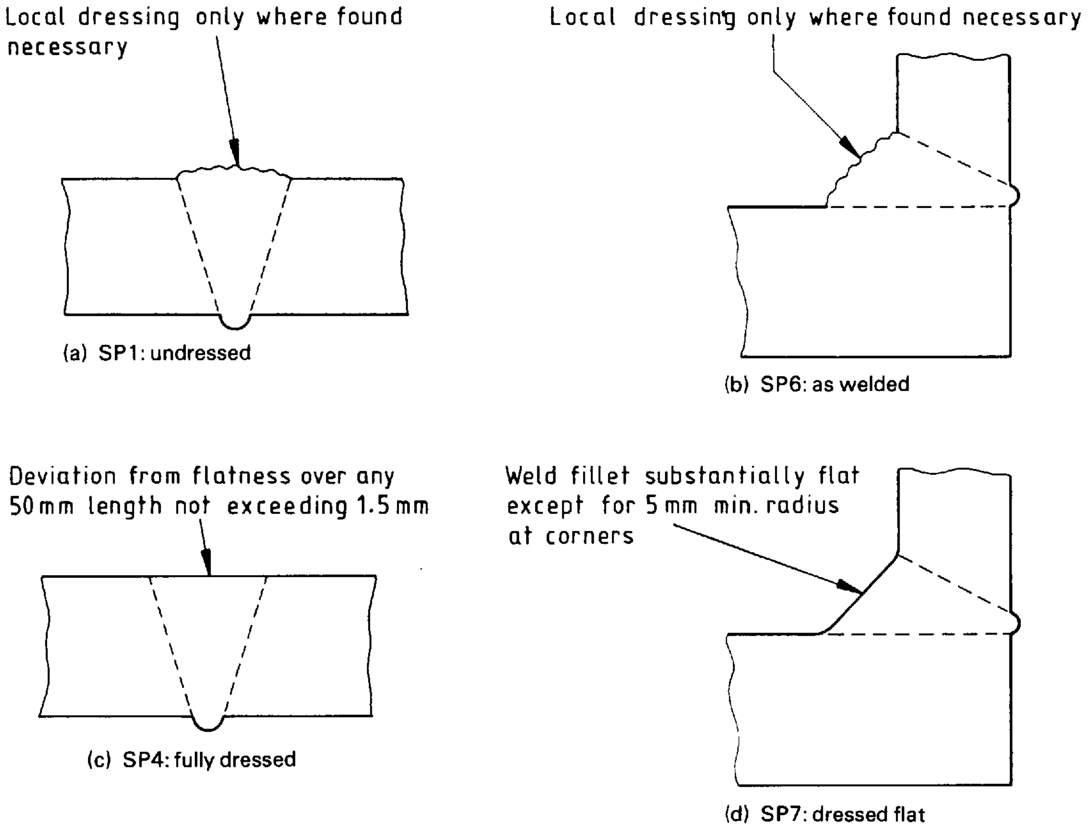


Figure 6.3.5.1 External finish categories

equal to or better than 3.2 μm. For wall thicknesses greater than 100 mm R_a for the surface finish shall not exceed 6.3 μm.

(c) *Finish SP7*. The fillet weld shall be dressed smooth and flat across its width, except at the corners where a 5 mm min radius is necessary to blend into the parent material. R_a for the surface finish shall not exceed 3.2 μm.

6.3.5.2 *Bore finish*

Where ultrasonic examination is to be carried out, one of the following bore finishes local to the butt weld shall be provided:

(a) CB1: parallel counterbore with step well clear of the bounce position for full-skip examination of the near-side of the weld;

(b) CB2: parallel counterbore with step clear of weld root but not necessarily beyond the bounce position of CB1;

(c) CB3: parallel counterbore with step position carefully controlled such that the lower part of the weld may be inspected within half-skip range in front of the counterbore, and the upper part between half-skip and full-skip range with the bounce from the inside surface occurring behind the counterbore;

(d) CB4: tapered counterbore, consisting of a shallow, well defined, 5° taper.

These conditions are illustrated, and the relevant dimensions given, in figure 5 of BS 3923 : Part 1 : 1986.

6.4 Identification of materials

All ferritic alloy and austenitic stainless steel materials, including weld metal, shall be checked after fabrication or after erection to confirm the essential composition; this shall be achieved by the method described in either appendix C or appendix F of BS 7339 : 1990.

These checks shall include completed welds made on site between items previously checked after fabrication.

Appendices

Appendix A. Pressures in safety valve discharge piping

A.1 The design pressures for safety valve discharge piping may be calculated by the methods described in this appendix (see **2.7**).

Pressures calculated using the equations in **A.2** and **A.3** should be increased by 25 % before being used as design pressures in accordance with **2.7**.

A.2 The absolute pressure p (in N/mm^2) inside a pipe carrying a compressible fluid at the rate of G (in kg/s per square metre of cross section), originating from a vessel in which its absolute pressure and density at rest were p_0 (in N/mm^2) and ρ_0 (in kg/m^3), can be expressed as:

$$p = rG\sqrt{B} \times 10^{-6} \qquad (44)$$

where

$$r = \sqrt{\frac{p_0 \times 10^6}{\rho_0}}\ ; \qquad (45)$$

B is a factor (see table A.2) depending upon the ratio k of the specific heat capacities during the expansion and upon the friction length (see **A.3**) of the pipe.

A.3 The friction length l_f equals $4fl/d$ where $4f$ is the normal friction coefficient in the incompressible flow formula where the pressure loss is expressed as:

$$4f\,\frac{l}{d} \times \frac{\rho V^2}{2} \qquad (46)$$

where

l is the length (in m);

d is the internal diameter (in m);

ρ is the density (in kg/m^3);

V is the velocity (in m/s);

and includes the usual allowance for bends and fittings and for the resistance through any silencer where this might be fitted and is calculated from the Reynolds number Gd/μ, where μ is the dynamic viscosity (in N·s/m^2), and the pipe roughness. The friction length is measured from the point at which a critical pressure would develop with the approximate values G and k.

The value of the critical pressure p_c (in N/mm^2) is given by equation (44) using for B the value at $l_f = 0$, and where the ambient pressure p_a (in N/mm^2) around the outlet of a pipe exceeds p_c a length l_f' corresponding to:

$$B_a = \left(\frac{p_a \times 10^6}{rG}\right)^2 \qquad (47)$$

is added to l_f before obtaining the value of B from which to calculate the pressure at any point.

A.4 Consider the following example. To calculate the pressure p at the upstream end of a straight pipe of 0.125 m diameter and 20 m long, exhausting to atmosphere the steam from a safety valve mounted on a superheater outlet where the absolute pressure is 7 N/mm^2 and the temperature 500 °C, the maximum quantity delivered by the valve being (a) 7 kg/s and (b) 1 kg/s:

	(a)	(b)
r (m/s)	580	580
G (kg/(m^2·s))	570	81.5
k	1.3	1.3
p_a(N/mm^2)	0.1	0.1
B_a	0.0915	4.475
l_f' corresponding to B_a	0 (since $B_a < B_c$)	2.342
l_f (with $4f = 0.016$)	2.560	2.560
$l_f + l_f'$	2.560	4.902
Corresponding B	4.743	7.470
p (N/mm^2)	0.72	0.129

A.5 The pressure in a small-bore pipe discharging into a pipe of larger bore may be calculated in the same way, the ambient pressure p_a being taken for the purpose as the pressure at the upstream end of the larger pipe, including an allowance for sudden enlargement which, if estimated on the conventional incompressible basis, will be on the safe side. A critical pressure may or may not be found on the exit of the small-bore pipe or at any enlargement.

A.6 For the purposes of exhaust pipe design, and where certified discharge capacity is not available (see **2.7.2**) the mass flow discharge M (in kg/s) by a safety valve is to be taken as:

$$M = \frac{A_v p_0 \times 10^6}{1.6r} \qquad (48)$$

$$= 625\,A_v\sqrt{p_0 \rho_0} \qquad (49)$$

where

A_v is the smallest area (in m^2) available for flow through the valve.

Table A.2 Compressible flow factors

$l_f = 4f\frac{l}{d}$	$B = \left(\frac{p \times 10^6}{rG}\right)^2$				
	k = 1.000 (see note)	k = 1.100	k = 1.200	k = 1.300	k = 1.400
0	1.000	0.866	0.758	0.669	0.595
0.01	1.148	1.010	0.899	0.807	0.789
0.02	1.214	1.074	0.961	0.868	0.789
0.03	1.265	1.125	1.011	0.917	0.837
0.04	1.310	1.169	1.054	0.959	0.878
0.05	1.350	1.208	1.092	0.996	0.915
0.06	1.388	1.245	1.128	1.031	0.950
0.07	1.422	1.279	1.162	1.064	0.982
0.08	1.455	1.311	1.193	1.095	1.013
0.09	1.486	1.342	1.213	1.125	1.042
0.10	1.516	1.371	1.252	1.153	1.070
0.12	1.573	1.427	1.307	1.207	1.123
0.14	1.626	1.479	1.358	1.258	1.173
0.16	1.677	1.529	1.407	1.306	1.221
0.18	1.726	1.577	1.454	1.352	1.266
0.20	1.772	1.623	1.500	1.397	1.310
0.30	1.986	1.833	1.707	1.602	1.513
0.40	2.179	2.023	1.895	1.787	1.695
0.50	2.358	2.200	2.069	1.959	1.866
0.60	2.528	2.367	2.234	2.123	2.028
0.70	2.689	2.527	2.393	2.280	2.184
0.80	2.846	2.682	2.546	2.432	2.335
0.90	2.998	2.833	2.695	2.580	2.481
1.00	3.146	2.979	2.841	2.724	2.624
1.20	3.434	3.264	3.123	3.004	2.902
1.40	3.711	3.539	3.396	3.275	3.171
1.60	3.982	3.807	3.662	3.539	3.434
1.80	4.246	4.069	3.922	3.797	3.691
2.00	4.505	4.326	4.177	4.051	3.943
2.5	5.136	4.953	4.800	4.671	4.560
3	5.749	5.562	5.405	5.272	5.159
4	6.937	6.743	6.580	6.443	6.325
5	8.091	7.891	7.724	7.582	7.461
6	9.222	9.017	8.846	8.701	8.576
7	10.34	10.13	9.952	9.803	9.676
8	11.44	11.22	11.05	10.89	10.76
9	12.53	12.31	12.13	11.98	11.84
10	13.61	13.39	13.21	13.05	12.91
15	18.94	18.71	18.52	18.35	18.20
20	24.19	23.94	23.74	23.57	23.42
30	34.54	34.28	34.07	33.89	33.73
40	44.80	44.53	44.31	44.12	43.95
50	55.01	54.73	54.50	54.30	54.13
60	65.18	64.89	64.55	64.45	64.28
70	75.32	75.03	74.79	74.58	74.40
80	85.45	85.15	84.90	84.69	84.51
90	95.56	95.26	95.00	94.79	94.61
100	105.7	105.4	105.1	104.9	104.7
150	156.1	155.7	155.5	155.2	155.0
200	206.3	206.0	205.7	205.5	205.3
300	306.7	306.4	306.1	305.8	305.6
500	507.2	506.8	506.5	506.3	506.0
1000	1008	1008	1007	1007	1007

NOTE. Or isothermic.

Appendix B. Derivation of material nominal design stresses

B.1 General

This appendix describes the principles used to derive the nominal design stresses given in table 3.2 which, unless otherwise stated, are related to the relevant property values given in:

BS 1503 : 1989, BS 1504 : 1976, BS 3601 : 1987, BS 3602 : Part 1 : 1987, BS 3602 : Part 2 : 1991, BS 3604 : Part 1 : 1990, BS 3604 : Part 2 : 1991 and BS 3605 : Part 1 : 1991.

Appropriate amendments to this appendix will be issued as necessary to cover future revisions of the above standards or additions to table 3.2.

B.2 Terminology

R_m is the minimum tensile strength (in N/mm^2) specified, for the grade of steel concerned, at room temperature (tested in accordance with BS EN 10 002-1)

R_e is the minimum yield or proof stress (in N/mm^2) specified for the grade of steel concerned at room temperature (tested in accordance with BS EN 10 002-1)

$R_{e(T)}$ is the yield stress (in N/mm^2) at temperature T (in °C) of the grade of steel concerned (related to values obtained when tested in accordance with BS EN 10002-5); applicable to carbon, carbon manganese and ferritic alloy steels and austenitic stainless steels

S_{Rt} is the mean value of stress (in N/mm^2) required to produce rupture in time t (in h) at temperature T (in °C) for the grade of steel in question (testing in accordance with BS 3500)

f_E is the nominal design stress (in N/mm^2) corresponding to the short-term tensile strength characteristics

f_F is the nominal design stress (in N/mm^2) corresponding to the creep characteristics

f is the nominal design stress (in N/mm^2) which has been taken as the lower of f_E and f_F

B.3 Time-independent design stress, f_E

B.3.1 General

British Standards listed in **B.1** which have been revised in or after 1978 specify minimum elevated temperature yield/proof stress values derived in most cases in accordance with the procedures specified in BS 3920 : Part 1.

These values show some differences from the properties specified in previous standards which were based on individual assessments of the data then available. The procedure described in BS 3920 is essentially empirical and properties derived by it are regarded as characteristic values (to be used for quality control purposes as specified in the relevant materials standards) rather than as critical properties in the design context. Nevertheless it is reasonable and convenient to base permissible design stresses directly on these characteristic yield/proof stress values unless this would result in design stresses for which there is no justification in terms of previous experience and current understanding of structural behaviour. This has been done except in a few cases where design stresses based on the simple relationships detailed in **B.3.2** would have resulted in an unwarranted reduction in the strength levels which have previously been established for the materials in question.

The time-independent design stress criteria may be applied to materials not included in the standards listed in **B.1** provided they comply with **3.1.2**. Values of $R_{e(T)}$ for such materials shall be verified by tests in accordance with BS EN 10002-5 at the appropriate temperature, unless the values were derived in accordance with BS 3920.

B.3.2 Carbon, carbon manganese and ferritic alloy steels

B.3.2.1 *Material with specified elevated temperature values.* The time-independent design stress is determined as follows.

(a) Up to and including 50 °C:

$$f_E = \frac{R_e}{1.5} \text{ or } \frac{R_m}{2.35} \qquad (50)$$

whichever is the lower.

(b) 150 °C and above:

$$f_E = \frac{R_{e(T)}}{1.5} \text{ or } \frac{R_m}{2.35} \qquad (51)$$

whichever is the lower.

(c) Between 50 °C and 150 °C: f_E has been based on linear interpolation between values obtained from equations (50) and (51).

B.3.2.2 *Material without specified elevated temperature values* (see note). The time-independent design stress is determined as follows.

(a) Up to and including 50 °C:

$$f_E = \frac{R_e}{1.5} \text{ or } \frac{R_m}{2.35} \qquad (52)$$

whichever is the lower.

(b) 150 °C and above:

$$f_E = \frac{R_{e(T)}}{1.6} \text{ or } \frac{R_m}{2.35} \qquad (53)$$

whichever is the lower.

(c) Between 50 °C and 150 °C: f_E has been based on linear interpolation between values obtained from equations (52) and (53).

NOTE. Values for $R_{e(T)}$ have been taken as equal to those specified for otherwise similar materials having specified elevated temperature values, except where:

(1) no $R_{e(T)}$ values are available; or

(2) design stresses in table 3.2 for similar materials having specified elevated temperature values are not directly based on specified $R_{e(T)}$ values; or

(3) the resultant values for f_E would be less than those indicated by established and successful past practice for equivalent materials.

In such cases, design stress values have been based on consideration of past practice in equivalent materials, and/or properties of equivalent materials in other product forms, and/or values permitted for equivalent materials in other national standards.

B.3.2.3 *Austenitic stainless steels.* The time-independent design stress is determined as follows.

(a) Material with specified elevated temperature values.

(1) Up to and including 50 °C:

$$f_E = \frac{R_e}{1.5} \text{ or } \frac{R_m}{2.5} \quad (54)$$

whichever is the lower.

(2) 150 °C and above:

$$f_E = \frac{R_{e(T)}}{1.35} \text{ or } \frac{R_m}{2.5} \quad (55)$$

whichever is the lower.

(3) Between 50 °C and 150 °C: f_E has been based on linear interpolation between values obtained from equations (54) and (55).

(b) Material without specified elevated temperature values (see note).

(1) Up to and including 50 °C:

$$f_E = \frac{R_e}{1.5} \text{ or } \frac{R_m}{2.5} \quad (56)$$

whichever is the lower.

(2) 150 °C and above:

$$f_E = \frac{R_{e(T)}}{1.45} \text{ or } \frac{R_m}{2.5} \quad (57)$$

whichever is the lower.

(c) Between 50 °C and 150 °C: f_E has been based on linear interpolation between values obtained from equations (56) and (57).

NOTE. Values for $R_{e(T)}$ have been taken as equal to those specified for otherwise similar materials having specified elevated temperature values, except where values of $R_{e(T)}$ are not available when f_E has been based on conservative interpretation of other available information.

B.4 Time-dependent design stress, f_F

The time-dependent design stress is determined as follows.

$$f_F = \frac{S_{Rt}}{1.3} \quad \text{(see notes 1 and 2)} \quad (58)$$

NOTE 1. The appropriate S_{Rt} properties agreed by Subcommittee 10 of Technical Committee 17 of the International Organization for Standardization (ISO) have been used wherever possible. These do not necessarily correspond to those specified in the British Standards listed in **B.1**. In general time-dependent values are not given for materials that are unsuitable or are unlikely to be used in the creep range.

NOTE 2. In most cases the S_{Rt} properties agreed by ISO for lifetimes in excess of 100 000 h have been obtained by extended extrapolation of time (more than three times on actual data) and those towards the upper end of the temperature range by extended stress extrapolation. Tabulated design stresses that are significantly lower than values well established by experience are identified in table 3.2 which permits values up to 10 % higher to be used provided fitness-for-continued-service reviews are instituted at two-thirds of the agreed design lifetime.

Appendix C. Examples of branch pipe design

C.1 Example 1 (see figure C.1)

The following examples are for cases where branches are normal to the main, thus

$\sin\gamma = 1.00$
$d_{2\gamma} = d_2$
$D_{2\gamma} = D_2$

C.1.1 Data

Assumed design conditions:

Design pressure 4.2 N/mm²
Design stress 95.9 N/mm²

C.1.2 Step 1: check whethe branches affect each other

Expression (15): branches affect each other if

$$\frac{L}{d_{2m} + d_{2n}} < 1$$

$$\frac{0}{127^* + 266^*} = 0$$

Branches affect each other, therefore **4.8.5.2** applies.

C.1.3 Step 2: calculate thickness of main

Evaluation of factors

$$\frac{f_1}{p} = \frac{95.9}{4.2} = 22.83$$

$$\frac{d_{2A}}{d_1} \approx 1$$

From figure 4.8.5.1, curve c

$x = 0.49$

Equation (18)

$$t_{m1} = \frac{pD_1}{2f_1e_1x + p}$$

$$= \frac{4.2 \times 273}{2 \times 95.9 \times 1.0 \times 0.49 + 4.2} = 11.68 \text{ mm}$$

The note to **4.8.5.2** suggests that t_{m1} should be multiplied by 1.25 $\frac{d_2}{d_1}$ to limit iteration.

Therefore $t_{m1} = 11.68 \times 1.25$ = 14.6 mm

Mean thickness of main with tolerance of ± 12.5 %

$$= \frac{14.6}{0.875} = 16.69 \text{ mm}$$

(Say 17.5 mm)

C.1.4 Step 3: calculate thickness of branches

$t_a = 17.5 \times 0.875$ = 15.31 mm

Equation (22)

$$\varepsilon = \frac{2t_a}{D_1 - t_a}$$

$$= \frac{2 \times 15.31}{273 - 15.31} = 0.119$$

* Assumed bore size.

Equation (26)

$$Y = \frac{p(d_1 + t_a)}{2f_1e_1t_a}$$

$$= \frac{4.2\{273 - (2 \times 15.31) + 15.31\}}{2 \times 95.9 \times 1.0 \times 15.31} = 0.369$$

From step 1 (see **C.1.2**) the branches require to be taken as a pair. From table 4.8.5.2

$C = 1$

Equation (25)

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

$g_{AB} = 1 - 1(1 - 0.369)$ = 0.369

$= n_A = n_B$ = 0.369

$\frac{d_{2A}}{d_1}$ and $\frac{d_{2B}}{d_1}$ are > 0.3, therefore $J = 2.2$.

Equation (27)

$$x_a = \frac{J}{Y}$$

$$= \frac{2.2}{0.369} = 5.962$$

Consider branch A.

From figure 4.8.5.2(1)

$\frac{d_2}{d_1} > 0.7$

$Z_A = 36.6$

Equation (21)

$$K = \sqrt{\frac{\varepsilon}{Zn}}$$

$$K_A = \sqrt{\frac{0.119}{36.6 \times 0.369}} = 0.0939$$

Equation (20)

$$t_{m2} = \frac{K}{2 - K} d_2$$

$$t_{m2A} = \frac{0.0939}{2 - 0.0939} d_{2A} = 0.0493 d_{2A}$$

$D_{2A} = d_{2A} + 2t_{m2A}$

Substituting for t_{m2A}

$D_{2A} = d_{2A} + (2 \times 0.0493 d_{2A})$

$273 = 1.0986 d_{2A}$

$$d_{2A} = \frac{273}{1.0986} = 248.5 \text{ mm}$$

$$t_{m2A} = \frac{D_{2A} - d_{2A}}{2}$$

$$= \frac{273 - 248.5}{2} = 12.25 \text{ mm}$$

With tolerance ± 12.5 %

$$t_{2A} = \frac{12.25}{0.875} = 14.0 \text{ mm}$$ (Say 14.2 mm)

Consider branch B.

From figure 4.8.5.2(1)

$$\frac{d_2}{d_1} < 0.7$$

$$Z_B = 70.5$$

Equation (21)

$$K = \sqrt{\frac{\varepsilon}{Zn}}$$

$$K_B = \sqrt{\frac{0.119}{70.5 \times 0.369}} = 0.0676$$

Equation (20)

$$t_{m2} = \frac{K}{2 - K} d_2$$

$$t_{m2B} = \frac{0.0676}{2 - 0.0676} d_{2B} = 0.035 d_{2B}$$

$$D_{2B} = d_{2B} + 2t_{m2B}$$

Substituting for t_{m2B}

$$D_{2B} = d_{2B} + (2 \times 0.035 d_{2B})$$

$$139.7 = 1.07 d_{2B}$$

$$d_{2B} = \frac{139.7}{1.07} = 130.56 \text{ mm}$$

$$t_{m2B} = \frac{D_{2B} - d_{2B}}{2}$$

$$= \frac{139.7 - 130.56}{2} = 4.57 \text{ mm}$$

With tolerance ± 12.5 %

$$t_{2B} = \frac{4.57}{0.875} = 5.22 \text{ mm}$$ (Say 5.4 mm)

C.1.5 Step 4: check for compliance with 4.8.3

Branch A

$$\frac{t_{2A}}{t_1} = \frac{14.2}{17.5} = 0.811$$

$$2 - \frac{D_{2A}}{D_1} = 2 - \frac{273}{273} = 1.00$$

Branch A complies with **4.8.3** but bore of branch is larger than bore of main. Therefore increase thickness of branch to 17.5 mm.

Branch B.

$$\frac{t_{2B}}{t_1} = \frac{5.4}{17.5} = 0.309$$

$$2 - \frac{D_{2B}}{D_1} = 2 - \frac{139.7}{273} = 1.49$$

Branch B complies with **4.8.3**.

C.1.6 Summary

Main 273 mm outside dia. x 17.5 mm mean wall thickness

Branch A 273 mm outside dia. x 17.5 mm mean wall thickness

Branch B 139.7 mm outside dia. x 5.4 mm mean wall thickness

C.2 Example 2 (see figure C.2)

C.2.1 Data

Assumed design conditions:

Design pressure	27 N/mm^2
Design stress	165.5 N/mm^2

C.2.2 Step 1: check whether branches affect each other

Expression (15): branches affect each other if

$$\frac{L}{d_{2m} + d_{2n}} < 1$$

Consider branches V and W

$$\frac{L}{d_{2V} + d_{2W}} = \frac{305 - 194}{194 + 194} = 0.286$$

Branches affect each other, therefore **4.8.5.2** applies.

C.2.3 Step 2: calculate thickness of main

Evaluation of factors

$$\frac{f_1}{p} = \frac{165.6}{27} = 6.133$$

$$\frac{d_{2U}}{d_1}, \frac{d_{2V}}{d_1}, \frac{d_{2W}}{d_1}, \frac{d_{2Y}}{d_1} \text{ and } \frac{d_{2Z}}{d_1} = \frac{194}{300^*} = 0.647$$

From figure 4.8.5.1, curve b

$$x = 0.661$$

Equation (18)

$$t_{m1} = \frac{pD_1}{2f_1e_1x + p}$$

$$= \frac{27 \times 406.4}{(2 \times 165.6 \times 1 \times 0.661) + 27} = 44.62 \text{ mm}$$

Mean thickness of main with tolerance of ± 10 %

$$= \frac{44.62}{0.9} = 49.58 \text{ mm}$$ (Say 50 mm)

Check that $\frac{d_2}{d_1}$ lies between 0.3 and 0.7 to verify use of curve b of figure 4.8.5.1

$$\frac{d_2}{d_1} = \frac{194}{406.4 - 2(50 \times 0.9)} = 0.613$$

* Assumed bore size.

C.2.4 Step 3: calculate thickness of branches

$t_a = 50 \times 0.9$ $= 45$ mm

Equation (22)

$$\epsilon = \frac{2t_a}{D_1 - t_a}$$

$$= \frac{2 \times 45}{406.4 - 45} = 0.249$$

Equation (26)

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

$$= \frac{27\{406.4 - (2 \times 45) + 45\}}{2 \times 165.6 \times 1 \times 45} = 0.655$$

From step 1 (see **C.2.2**) the branches affect each other. From table 4.8.5.2

Equation (25)

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

$g_{UV}, g_{VW}, g_{WY}, g_{WZ} = 1 - 0.979\,(1 - 0.655)$ $= 0.662$

$n = g_1 \times g_2 \times g_3$

$n_U = 0.662$ $= 0.662$

$n_V = 0.662 \times 0.662$ $= 0.438$

$n_W = 0.662 \times 0.662$ $= 0.438$

$n_Y = 0.662 \times 0.662$ $= 0.438$

$n_Z = 0.662$ $= 0.662$

For all branches $\frac{d_2}{d_1}$ is > 0.3. Therefore $J = 2.2$.

Equation (27)

$$x_a = \frac{J}{Y}$$

$$= \frac{2.2}{0.655} = 3.359$$

From figure 4.8.5.2(1), lower curve

Z $= 4.248$

Consider branches U and Z. Equation (21)

$$K = \sqrt{\frac{\varepsilon}{Zn}}$$

$$K_U \text{ and } K_Z = \sqrt{\frac{0.249}{248 \times 0.662}} = 0.298$$

Equation (20)

$$t_{m2} = \frac{K}{2 - K}\, d_2$$

$$t_{m2u} \text{ and } t_{m2Z} = \frac{0.298 \times 194}{2 - 0.298} = 33.97 \text{ mm}$$

Consider branches V, W, Y.

Equation (21)

$$K = \sqrt{\frac{\varepsilon}{Zn}}$$

$$K_V, K_W \text{ and } K_Y = \sqrt{\frac{0.249}{4.248 \times 0.438}} = 0.366 \text{ mm}$$

Equation (20)

$$t_{m2} = \frac{K}{2 - K}\, d_2$$

$$t_{m2V}, t_{m2W} \text{ and } t_{m2Y} = \frac{0.366 \times 194}{2 - 0.366} = 43.45 \text{ mm}$$

C.2.5 Step 4: check for compliance with 4.8.3

Branches U and Z

$$\frac{t_2}{t_1} = \frac{33.97}{50} = 0.679$$

$$2 - \frac{D_2}{D_1} = 2 - \frac{194 + (2 \times 33.97)}{406.4} = 1.355$$

Branches U and Z comply with **4.8.3**.

Branches V, W and Y

$$\frac{t_2}{t_1} = \frac{43}{50} = 0.86$$

$$2 - \frac{D_2}{D_1} = 2 - \frac{194 + (2 \times 43.45)}{406.4} = 1.309$$

Branches U and Z comply with **4.8.3**.

	Branch pairs									
	UV	**UW**	**UY**	**UZ**	**VW**	**VY**	**VZ**	**WY**	**WZ**	**YZ**
$d_{2m} + d_{2n}$ L	388 111	388 > 388	388 > 388	388 > 388	388 111	388 > 388	388 > 388	388 111	388 > 388	388 111
$\frac{L}{d_{2m} + d_{2n}}$	0.286	> 1	> 1	> 1	0.286	> 1	> 1	0.286	> 1	0.286
C	0.979	0	0	0	0.979	0	0	0.979	0	0.979

C.2.6 Summary

Body 406.4 mm outside diameter × 50 mm mean wall thickness

Branches U, Z 194 mm bore × 34 mm minimum wall thickness

Branches V, W, Y 194 mm bore × 44 mm minimum wall thickness

Alternatively, if it is necessary to use hot finished seamless tube for the branches.

Branches U and Z outside diameter

$$= 194 + \left(2 \times \frac{34}{0.9}\right) = 269.6$$

(Say 273 mm outside diameter)

Use 273 mm outside diameter × 39 mm mean wall thickness

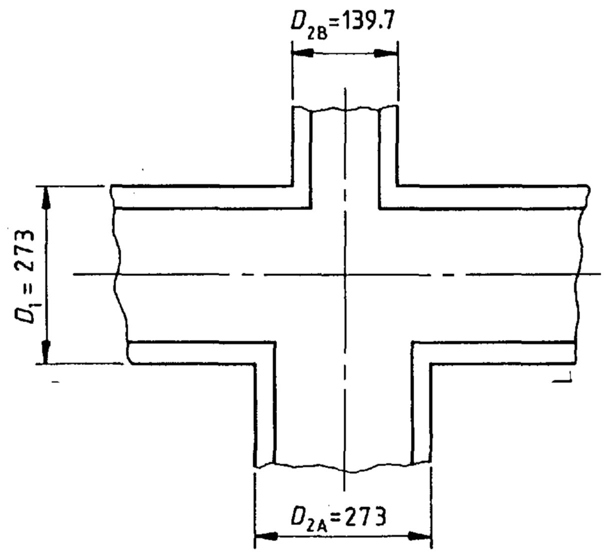
Branches V, W and Z outside diameter

$$= 194 + \left(2 \times \frac{44}{0.9}\right) = 291.8$$

(Say 298.5 mm outside diameter)

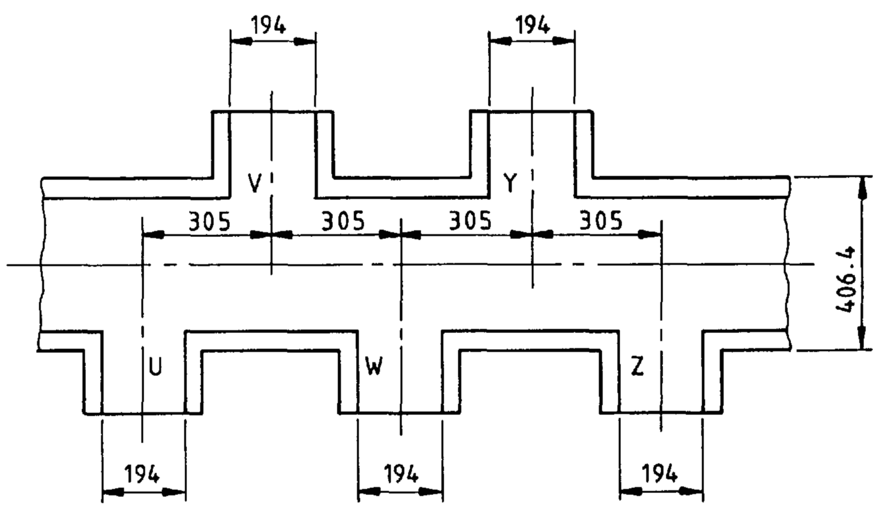
Use 298.5 mm outside diameter × 52 mm mean wall thickness

A further solution may be obtained by recalculating using modified bore sizes estimated to result in outside diameters equal to the standard rolling sizes.



All dimensions are in millimetres.

Figure C.1 Example 1 of branch pipe design



All dimensions are in millimetres.

Figure C.2 Example 2 of branch pipe design

Appendix D. Coefficient of linear expansion for pipes

D.1 The coefficient of linear expansion of steel depends on a number of factors such as the chemical composition, heat treatment and the method of manufacture.

The following value of the coefficient of expansion, *a*, per degree Celsius for expansion from 0 °C to *T* °C will be of sufficient accuracy for purposes of calculation:

$a = (11.56 + 0.0055T) \times 10^{-6}$ for carbon and low alloy steel

$= (10.65 + 0.0030T) \times 10^{-6}$ for steel 762

$= (9.74 + 0.0013T) \times 10^{-6}$ for cast iron

$= (16.21 + 0.0042T) \times 10^{-6}$ for austenitic steel

D.2 Table 4.10 gives the actual amount of expansion per 1 m length for a rise of temperature from 20 °C to the temperature given.

D.3 The expansion per unit length between any two temperatures T_1 °C and T_2 °C is given by:

$a_2 T_2 - a_1 T_1$

where

a_1 is the coefficient of expansion between 0 °C and T_1 °C;

a_2 is the coefficient of expansion between 0 °C and T_2 °C.

Appendix E. Recommended proof and rupture data in connection with flexibility analysis (see 4.11.2)

E.1 Steel tubes and pipes

The recommended proof and rupture data in connection with flexibility analysis for steel tubes and pipes are given in tables E.1(1) to E.1(3).

Table E.1(1) 0.2 % proof stress values for steel tubes and pipes

Steel grade	Values for 0.2 % proof stress (N/mm²) at temperatures (°C) not exceeding										
	20	100	150	200	250	300	350	400	450	500	550
3601-320	176	168	158	147	125	100	91	88			
3601-360	195	187	176	165	145	122	111	109			
3601-430	239	224	210	189	169	154	142	134			
3602-360	212	198	187	170	150	132	120	112	108		
3602-430	255	239	224	202	180	164	151	143	137		
3602-490	315	262	247	230	214	196	182				
3602-500	343	313	291	267	244	222	203	188	177		
3604 Pt 1-591	440	422	412	402	392	382	373	343			
3604 Pt 1-620-440	287	264	253	245	236	192	182	174	168	166	163
3604 Pt 1-621	272	248	237	228	218	174	165	157	152	150	149
3604 Pt 1-660	297	282	276	267	241	225	216	209	203	200	197
3604 Pt 1-622	272	261	253	245	236	230	224	218	205	189	167
3604 Pt 1-762	448	406	388	374	360	348	340	326	309	281	243
3604 Pt 2-620	340	280	270	258	247	228	215	211	206		
3604 Pt 2-621	340	315	305	291	280	266	255	251	245		
3604 Pt 2-622	310	292	283	275	266	260	252	245	231		

Table E.1(2) 1 % proof stress values for steel tubes and pipes

Steel grade	Values for 1 % proof stress (N/mm²) at temperatures (°C) not exceeding												
	20	100	150	200	250	300	350	400	450	500	550	600	650
3605-304 S11	215	168	150	137	128	122	116	110	108				
S31	230	178	160	147	139	132	125	120	117				
S51	230	178	160	147	139	132	125	120	117	115	112	109	104
3605-316 S11, S13	225	177	161	149	139	133	127	123	119				
S31, S33	240	189	172	159	150	143	137	133	129				
S51, S52	240	189	172	159	150	143	137	133	129	125	121	119	116
3605-321 S31	235	192	180	172	164	158	152	148	144				
S51 (1010)	235	192	180	172	164	158	152	148	144	140	138	135	130
S51 (1105)	190	149	139	131	125	118	114	110	107	105	104	102	100
3605-347 S31	240	204	192	182	172	166	162	159	157				
S51	240	204	192	182	172	166	162	159	157	155	153	151	
3605-215 S15	270	232	210	195	190	187	184	182	179	178	175	170	165

Table E.1(3) Average rupture stress values for steel tube and pipe

Steel grade	Values of average rupture stress (N/mm²) at temperatures (°C) not exceeding																									Lifetime (h)
	380	390	400	410	420	430	440	450	460	470	480	490	500	510	520	530	540	550	560	570	580	590	600	610	620	
3602-360	171	155	141	127	114	102	90	78	67	57	47	36														100 000
	164	149	134	121	108	96	84	73	62	52	41	29														150 000
3602-430	159	144	130	116	104	92	80	69	58	48	37	23														200 000
	155	140	126	113	101	89	77	66	58	45	34															250 000
3602-500	227	203	179	157	136	117	100	85	73	63	55	47	41	32												100 000
	215	190	167	144	124	105	89	76	65	56	49	42	34													150 000
	206	181	157	135	115	97	82	70	60	52	44	37														200 000
	199	174	150	128	108	91	77	66	56	48	41	32														250 000
3604-591	Average rupture stress values, not available																									
3604-620 3604-621											210	177	146	121	99	81	67	54	43	35						100 000
											194	161	132	108	87	71	57	46	38	31						150 000
											180	148	122	99	79	64	52	42	34	28						200 000
											170	139	114	91	74	59	48	39	32	26						250 000
3604-622								221	204	186	170	153	137	122	107	93	79	69	59	51	44					100 000
								209	192	175	158	141	126	110	95	82	73	63	54	47	40					150 000
								203	186	169	152	135	119	103	89	77	68	58	50	43	37					200 000
								198	181	164	147	130	113	98	84	74	64	55	47	41	35					250 000
3604-660								321	294	268	242	217	193	170	149	130	113	99	86	73						100 000
								309	282	256	230	205	181	158	138	120	104	90	77	61						150 000
								301	274	247	221	196	172	150	130	113	98	85	71							200 000
								295	267	240	214	189	166	144	125	108	93	80	65							250 000
3604-762											294	271	248	225	202	180	159	139	121	104	88	75	63	52	43	100 000
											279	259	239	219	197	175	150	128	110	94	80	68	57	48	39	150 000
											276	265	234	213	190	167	143	122	104	89	76	64	53	44	36	200 000
											268	249	229	208	185	161	137	117	100	84	72	60	50	41	33	250 000

Table E.1(3) Average rupture stress values for steel tube and pipe *(concluded)*

Steel grade	Values of average rupture stress (N/mm²) at temperatures (°C) not exceeding																								Lifetime (h)
	520	530	540	550	560	570	580	590	600	610	620	630	640	650	660	670	680	690	700	710	720	730	740	750	
3605-304 S51				143	133	124	116	107	99	92	85	78	71	65	59	54	50	46	43	40	37				100 000
				136	127	118	109	101	94	86	79	72	66	60	55	51	47	43	40	38					150 000
				131	122	113	105	97	90	82	75	69	63	57	52	48	44	41	39	36					200 000
				127	118	110	102	94	86	79	72	66	60	55	50	46	43	40	38						250 000
3605-316 S51 S52				196	180	160	147	132	118	106	96	86	76	69	60	53	46	41	37	33	30	27	25	23	100 000
				187	171	152	139	124	110	97	86	76	68	60	53	47	41	36	32	28	25	24	21		150 000
				181	165	146	133	116	103	91	80	71	63	56	49	43	38	33	29	26	24	22	20		200 000
				176	159	140	127	110	97	86	76	67	59	52	46	40	35	31	28	25	23	21	19		250 000
3605-321 S51 (1010)		167	156	143	134	123	112	102	92	82	74	64	55	47	40	36	31	27	23						100 000
		152	141	132	122	112	102	93	83	73	64	55	47	41	35	30									150 000
	156	146	137	126	116	106	96	86	76	67	58	50	43	37	32	21									200 000
	150	140	131	121	111	101	92	81	72	62	54	46	40	34	29										250 000
3605-321 S51 (1105)						137	126	116	106	97	88	78	71	64	57	50	44	39	34						100 000
						130	119	109	99	89	80	73	65	57	50	44	38	33							150 000
						125	113	103	93	84	76	68	60	53	46	40	35	30							200 000
						120	109	99	89	80	72	64	57	60	43	37	32								250 000
3605-347 S51			181	168	154	142	129	118	106	96	86	77	69	61	53	46	40	35	30	25	22				100 000
			171	158	145	132	121	109	98	88	79	71	63	53	48	42	36	32	28	24					150 000
			164	151	138	127	114	103	93	83	75	66	58	51	44	38	33	29	25	22					200 000
			159	146	133	122	110	99	88	79	71	63	55	48	41	36	31	27	25						250 000
3605-215 S15									230	209	187	165	139	113	92	77	67	59	52	46					100 000
									218	196	173	148	121	97	80	68	60	53	46						150 000
									210	187	162	135	108	87	73	63	55	49	42						200 000
									203	179	153	125	99	81	68	59	52	48							250 000

E.2 Steel castings complying with BS 1504

In the absence of published data, the following values of proof and rupture data in connection with flexibility analysis are recommended for steel castings complying with BS 1504.

(a) 0.2 % proof stress is given by:
$1.5 f \times F$

(b) 1 % proof stress is given by:
$1.35 f \times F$

(c) Average rupture stress is given by:
$1.3 f \times F$

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

f is the design stress (in N/mm²);
F is the casting quality factor (see **4.5**).

E.3 Steel forgings complying with BS 1503

The recommended proof and rupture data in connection with flexibility analysis for steel forgings complying with BS 1503 are given in tables E.3(1) to E.3(3).

Table E.3(1) 0.2 % proof stress values for steel forgings complying with BS 1503

Steel grade	Diameter or equivalent diameter (see note)	Values of 0.2 % proof stress (N/mm²) at temperatures (°C) not exceeding											
		20	100	150	200	250	300	350	400	450	500	550	600
164-490	⩽ 100	305	273	256	234	213	192	182	173	168			
	> 100 ⩽ 150	280	253	238	218	205							
221-410	⩽ 100	215	192	188	181	168	150	142	138	136			
	> 100	205	178	175	170	162							
221-430	⩽ 100	225	204	200	193	178	160	153	148	145			
	> 100	215	189	186	181	172							
221-460	⩽ 100	245	222	218	210	194	176	168	162	158			
	> 100	235	206	203	197	188							
221-490	⩽ 100	265	240	236	227	210	192	183	177	172			
	> 100	255	222	219	212	203							
221-510	⩽ 100	285	253	248	239	221	202	193	186	180			
223-410	⩽ 100	245	216	207	195	180	159	148	138	133			
	> 100	230	201	193	181	173							
223-430	⩽ 100	260	234	222	208	192	171	160	150	144			
	> 100	245	218	201	193	184							
223-460	⩽ 100	290	261	246	227	210	190	178	167	161			
	> 100	270	243	229	211	202							
223-490	⩽ 100	320	288	269	247	228	208	196	184	177			
	> 100	295	263	250	230	219							
223-510	⩽ 100	340	305	285	259	239	220	207	196	188			
224-410	⩽ 100	235	215	204	188	171	152	141	134	130			
	> 100	220	200	190	175	164							
224-430	⩽ 100	250	229	217	199	182	162	151	144	139			
	> 100	235	213	202	185	175							
224-460	⩽ 100	275	251	236	217	198	177	167	158	153			
	> 100	255	233	220	202	190							
224-490	⩽ 100	305	272	256	234	213	192	182	173	168			
	> 100	280	253	238	218	205							
224-510	⩽ 100	315	287	268	245	224	202	192	183	177			
225-440	⩽ 100	340	306	284	258	240	220	206	195	187			
	> 100	300	272	260	245	231	218						
620-440		275	241	224	213	197	184	170	162	157	151	146	145
620-540	⩽ 200	375	340	328	315	303	294	284	279	273	265	251	240
621-460		275	260	245	234	218	205	191	183	176	167	163	162
660-460		300	282	276	267	241	225	216	209	203	200	197	164
271-560		370	341	330	322	312	306	298	288	282	269	255	221
622-490		275	261	253	245	236	230	224	218	205	189	167	145
622-560		370	347	336	329	320	313	302	295	289	259	226	193
762-690	⩽250	490	407	388	374	360	349	340	328	309	280	243	177

NOTE. If a solid forging has a reasonably cylindrical section at the position from which test samples are to be taken, the diameter at that position is the dimension referred to in this table.

If a solid forging is not cylindrical, or is hollow, the table refers to the equivalent diameter, which should be estimated for the similar position on the forging using the rules given in BS 5046, a hollow cylinder being considered as a tube for the purposes of that standard.

Table E.3(2) 1 % proof stress values for steel forgings complying with BS 1503

Steel grade	Values of 1 % proof stress (N/mm^2) at temperatures (°C) not exceeding													
	20	100	150	200	250	300	350	400	450	500	550	600	650	700
304 S11	215	168	150	137	128	122	116	110	108					
304 S31	230	178	160	147	139	132	125	120	117					
304 S51	230	178	160	147	139	132	125	120	117	115	112	109	104	99
347 S31	240	204	192	182	172	166	162	159	157					
347 S51	240	204	192	182	172	166	162	159	157	155	153	151		
321 S51-490	190	149	139	131	125	118	114	110	107	105	104	102	100	97
321 S31	235	192	180	172	164	158	152	148	144					
321 S51-510	235	192	180	172	164	158	152	148	144	140	138	135	130	124
316 S11	225	177	161	149	139	133	127	123	119					
316 S13	225	177	161	149	139	133	127	123	119					
316 S31	240	189	172	159	150	143	137	133	129					
316 S33	240	189	172	159	150	143	137	133	129					
316 S51	240	189	172	159	150	143	137	133	129	125	121	119	116	113

Table 3.3(3) Average rupture stress values for steel forgings complying with BS 1503

The figure in parentheses refers to the note following this table.

Steel grade	Values of average rupture stress (N/mm^2) at temperatures (°C) not exceeding																									Lifetime (h)
	380	390	400	410	420	430	440	450	460	470	480	490	500	510	520	530	540	550	560	570	580	590	600	610	620	
Carbon(1)	227	203	179	157	136	117	100	85	73	63	55	47	41	32												100 000
	215	190	167	144	124	105	89	76	65	56	49	42	34													150 000
	206	181	157	135	115	97	82	70	60	52	44	37														200 000
	199	174	150	128	108	91	77	66	56	48	41	32														250 000
620-440 620-540 621-460											210	177	146	121	99	81	67	54	43	35						100 000
											194	161	132	108	87	71	57	46	38	31						150 000
											180	148	122	99	79	64	52	42	34	28						200 000
											170	139	114	91	74	59	48	39	32	26						250 000
660-460								321	294	268	242	217	193	170	149	130	113	99	86	73						100 000
								309	282	256	230	205	181	158	138	120	104	90	77	61						150 000
								301	274	247	221	196	172	150	130	113	98	85	71							200 000
								295	267	240	214	189	166	144	125	108	93	80	65							250 000
271-560			417	405	388	367	341	309	272	235	201	168	139	113	90	70	53	39								100 000
			402	391	375	354	328	298	263	225	188	154	123	99	78	57	41	30								150 000
			398	385	367	346	318	287	249	208	171	141	113	88	66	50	34	23								200 000
			391	378	359	337	311	281	245	204	168	136	108	85	63	45	30	18								250 000
622-490 622-560								221	204	186	170	153	137	122	107	93	79	69	59	51	44					100 000
								209	192	175	158	141	126	110	95	82	73	63	54	47	40					150 000
								203	186	169	152	135	119	103	89	77	68	58	50	43	37					200 000
								198	181	164	147	130	113	98	84	74	64	55	47	41	35					250 000
762-690													248	225	202	180	159	139	121	104	88	75	63	52	43	100 000
													239	219	197	175	150	128	110	94	80	68	57	48	39	150 000
													234	213	190	167	143	122	104	89	76	64	53	44	36	200 000
													229	208	185	161	137	117	100	84	72	60	50	41	33	250 000

Table E.3(3) Average rupture stress values for steel forgings complying with BS 1503 *(concluded)*

Steel grade	Values of average rupture stress (N/mm^2) at temperatures (°C) not exceeding																						Lifetime (h)
	540	550	560	570	580	590	600	610	620	630	640	650	660	670	680	690	700	710	720	730	740	750	
304 S51		143	133	124	116	107	99	92	85	78	71	65	59	54	50	46	43	40	37				100 000
		136	127	118	109	101	94	86	79	72	66	60	55	51	47	43	40	38					150 000
		131	122	113	105	97	90	82	75	69	63	57	52	48	44	41	39	36					200 000
		127	118	110	102	94	86	79	72	66	60	55	50	46	43	40	38						250 000
316 S51		196	180	160	147	132	118	106	96	86	76	69	60	53	46	41	37	33	30	27	25	23	100 000
		187	171	152	139	124	110	97	86	76	68	60	53	47	41	36	32	28	25	24	21		150 000
		181	165	146	133	116	103	91	80	71	63	56	49	43	38	33	29	26	24	22	20		200 000
		176	159	140	127	110	97	86	76	67	59	52	46	40	35	31	28	25	23	21	19		250 000
321 S51-490				137	126	116	106	97	88	78	71	64	57	50	44	39	34						100 000
				130	119	109	99	89	80	73	65	57	50	44	38	33							150 000
				125	113	103	93	84	76	68	60	53	46	40	35	30							200 000
				120	109	99	89	80	72	64	57	50	43	37	32								250 000
321 S51-510				123	112	102	92	82	74	64	55	47	40	36	31	27	23						100 000
				112	102	93	83	73	64	55	47	41	35	30									150 000
				106	96	86	76	67	58	50	43	37	32	27									200 000
				101	92	81	72	62	54	46	40	34	29										250 000
347 S51	181	168	154	142	129	118	106	96	86	77	69	61	53	46	40	35	30	25	22				100 000
	171	158	145	132	121	109	98	88	79	71	63	55	48	42	36	32	28	24					150 000
	164	151	138	127	114	103	93	83	75	66	58	51	44	38	33	29	25	22					200 000
	159	146	133	122	110	99	88	79	71	63	55	48	41	36	31	27	25						250 000

NOTE 1. The values given in this table are applicable to all the carbon steels given in table 3.2.

Appendix F. Worked example of stress calculation in a sectionalized pipe system

F.1 General

The calculation of bending moments and the identification of maxima where various modes of operation can apply becomes a lengthy exercise if undertaken manually, and it is expected that where such systems are required to be analysed recourse will have to be made to a computer analysis using a program developed to comply with this standard.

This appendix does, nevertheless, show how moment data are to be abstracted.

A specimen configuration is considered and moment data are tabulated to facilitate the various combinations required to carry out the calculations required by this standard. One particular point of high stress is investigated in depth, values are calculated for hot stress and stress range under all modes of operation as required by the standard and the limiting values specified by this standard for stress range and hot stress are also identified and calculated.

For the example considered in this appendix, and in particular for the point considered in depth, it will be seen that in practice many of the steps need not be taken if the calculation is to be carried out manually, e.g. it is seen that in every case the combined transverse stress is greater than the combined longitudinal stress, and obviously the latter need not be calculated beyond the first case here.

F.2 Identification of planes

The particular point considered in depth occurs on a bend where the in-plane and out-of-plane directions are easily identified. In-plane and out-of-plane directions are also easily identified at branch junctions, but there is no apparent planar logic to apply to a straight pipe.

However, as the calculation of stress levels at points that are subject to varying modes of operation requires the inclusion of moment levels not occurring simultaneously, it is necessary to have a recognized terminology for planar direction of straight sections.

While no direction is given in this standard on this identification of planes in straight pipes, the following separation of planes is intended.

If a plane is considered as lying between a straight pipe and the vertical axis then this plane is in 'in-plane' of that pipe.

Where a vertical straight pipe is being considered, then the planar direction is that of the upper end bend or junction. Where no such bend or junction exists, then the lower end bend or branch is taken to identify the vertical straight pipe plane.

F.3 Specimen configuration and design data

The specimen configuration is shown in figure F.3.

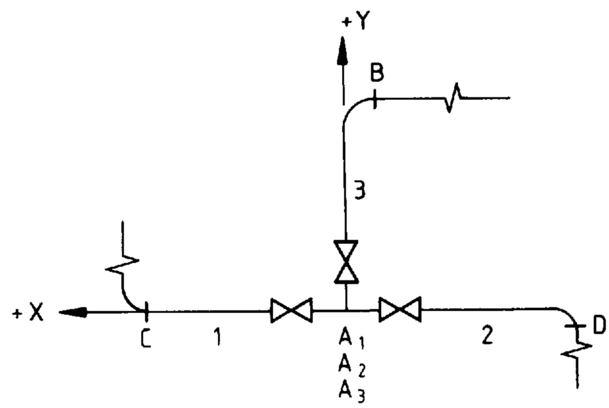


Figure F.3 Specimen configuration

Design conditions

Design life 100 000 h

Pipe	Pressure bar	Temperature °C
1 and 2	13	340
2	13	450
3	13	450
Tee A1, A2 and A3	13	450

Material: BS 3602 : Part 1 : 1987. Steel 430 HFS

Pipe dimensions

Pipe	Outside diameter mm	Pipe wall thickness mm	Tee wall mm
1 and 2	168.3	8	9.5
3	114.3	6.3	7.1

F.4 Ordinates of reference

The ordinates of reference are shown in figure F.4.

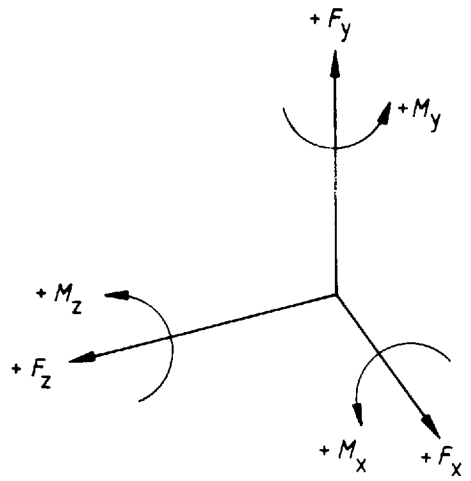


Figure F.4 Ordinates of reference

F.5 Modes of operation

The modes of operation are as follows:

(a) Pipe 1 cold (20 °C); pipes 2 and 3 at 450 °C and 13 bar.

(b) Pipe 2 cold (20 °C); pipes 1 and 3 at 250 °C and 13 bar.

(c) Pipe 2 cold (20 °C); pipe 1 at 340 °C and 13 bar; pipe 3 at 450 °C and 13 bar.

(d) All pipes cold 20 °C.

(e) All pipes hot at 13 bar; pipe 1 at 340 °C; pipes 2 and 3 at 450 °C.

F.6 Determination of moments

Moments tables F.6(1) to F.6(4) show the values and combinations.

All moments are expressed in N·mm × 10^6.

Table F.6(1) gives moments as calculated on the basis of complete thermal expansion of the all-hot mode (e) (see **F.5**). No credit is given for cold pull.

Table F.6(1) Stress range: cold-to-hot
(see **4.11.3.1**(a) (1))

Mode	Position	Moments (N·mm × 10^6)		
		M_x	M_y	M_z
Range (d) to (e)	A1	1.6	0.5	2.0
	A2	1.2	1.0	0.8
	A3	0.4	0.5	1.2
	B	1.3	0.3	1.0
	C	0.8	0.4	0.8
	D	1.6	0.2	0.3

In this case there is only one all-hot condition. Where there is more than one all-hot condition, or when there is no all-hot condition, then each cold-to-hot mode would need to be considered separately to establish the most onerous condition at any point (see note).

The moments given in table F.6(1) are used to calculate the maximum stress range as defined in **4.11.3.1**(a) (1) to comply with the limitations of **4.11.2**(a) (1) or (2).

NOTE. Where there is no cold-to-hot or where there is more than one cold-to-hot, the maximum moment in each plane for all modes (in the case of no cold-to-hot) and all-hot modes (in the case of more than one all-hot) should be first considered and, if the permissible limit is not exceeded, then the limits will not be exceeded under any individual mode. This will ensure that the necessity to identify the worst case will apply only where the permissible limit is exceeded.

Table F.6(2) gives moments calculated on the basis of complete thermal expansion for combined modes (a), (b), (c) and (e). No credit is given for the cold pull.

Table F.6(2) Stress range: sectionalized system, maximum difference (no cold pull allowance) (see **4.11.3.1**(a) (2))

Mode	Position	Moments (N·mm × 10^6)			
		M_x	M_y	M_z	
(a)	A1	+1.5	+0.4	+2.6	
	A2	+0.5	+0.2	−0.3	
	A3	−2.0	−0.6	−2.3	
	B	+1.2	+0.2	+1.0	
	C	−0.2	+0.2	+0.8	
	D	+1.7	+0.4	+0.5	
(b)	A1	+2.0	−0.2	−2.0	Values used to obtain greatest difference shown boxed, e.g. −0.6
	A2	−0.5	−0.4	+1.5	
	A3	−1.5	+0.6	+0.5	
	B	+1.6	−0.4	+1.2	
	C	−0.2	+0.3	−0.5	
	D	−0.3	+0.4	+1.5	
(c)	A1	−1.3	−0.3	−0.5	
	A2	+1.0	−1.0	+2.0	
	A3	+0.3	+1.3	−1.5	
	B	−1.5	+0.1	−0.2	
	C	+1.2	+0.3	+1.3	
	D	−2.0	−0.3	+1.2	
(e)	A1	+1.6	+0.5	+2.0	
	A2	−1.2	−1.0	−0.8	
	A3	−0.4	+0.5	−1.2	
	B	+1.3	−0.3	+1.0	
	C	+0.8	+0.4	+0.8	
	D	+1.6	−0.2	+0.3	
Greatest difference	A1	3.3	0.8	4.6	
	A2	2.2	1.2	2.8	
	A3	2.3	1.9	2.8	
	B	3.1	0.6	1.4	
	C	1.4	0.2	1.8	
	D	3.7	0.7	1.2	

4.11.3.1(a) (2) requires that 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 based on table F.6(1), the maximum stress range based on the maximum difference between bending moments in each plane shall be calculated.

The moments tabulated in table F.6(2) are therefore combined to show the maximum difference in each of the three planes and these differences are used in the calculation required by **4.11.3.1**(a) (2).

4.11.2 states that, at no point in the pipes under cold or any operating condition within the design limits, shall the lower of the values derived from **4.11.2**(a) (1) or (2) be exceeded.

In addition, the limiting requirements specific to the sectionalized system as defined in **4.11.3.1**(a) (2) shall be satisfied.

Table F.6(3) gives moments as calculated on the basis of complete thermal expansion of all-hot mode (e) minus the theoretical cold pull.

Table F.6(3) Hot stress all-hot: hot expansion minus cold pull (see **4.11.3.1**(b) (1))

Mode	Position	Moments (N·mm × 10^6)		
		M_x	M_y	M_z
All hot (e)	A1	0.6	0.2	0.8
	A2	0.5	0.4	0.3
	A3	0.8	0.2	0.5
	B	0.5	0.1	0.4
	C	0.3	0.2	0.3
	D	0.6	0.1	0.1

The moments tabulated in table F.6(3) will be used to calculate the hot stress as defined in **4.11.3.1**(b) (1) to comply with the limitation of **4.11.2**(b). This calculation is required only if the limitation of **4.11.2**(a) (2) is more onerous than that of **4.11.2**(a) (1).

NOTE. This all-hot mode need not be calculated for a sectionalized system where **4.11.3.1**(b) (2) has to be calculated, as it should always be less than this latter value and has to comply with the same limiting value.

Table F.6(4) gives moments as calculated on the basis of complete thermal expansion for combined modes (a), (b), (c) and (e) minus the theoretical cold pull in each case.

4.11.3.1(b) (2) requires that, 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 each plane under any hot condition of operation shall be considered in addition to the basic cold-to-hot condition pertaining to the moments given in table F.6(3).

The moments tabulated in table F.6(4) are therefore combined to show in each plane the maximum difference obtained from any two moments in that plane, but with only 0.5 times the lower of the two considered.

This difference is compared with the highest moment in each plane and the higher of the two values is used in the calculations to comply with **4.11.3.1**(b) (2).

This calculation is only required if the limitation of **4.11.2**(a) (2) is more onerous than that of **4.11.2**(a) (1).

Table F.6(4) Hot stress, sectionalized system, highest or difference (hot expansion, minus cold pull) (see **4.11.3.1**(b) (2)

Figures in parentheses refer to the notes following this table.

Mode	Position	Moments (N·mm x 10^6)		
		M_x	M_y	M_z
(a)	A1	−0.3(1)	+0.2(2)	+1.2(2)
	A2	+0.1	+0.1(1)	−0.2
	A3	+0.2(1)	−0.3(2)	−1.0(2)
	B	+0.8(2)	−0.1	−0.2(1)
	C	+0.3(2)	+0.2	+0.3
	D	−0.2	+0.1	−0.2(1)
(b)	A1	+0.6	+0.2	−0.1
	A2	+0.2(1)	−0.1	+0.2(1)
	A3	−0.8(2)	−0.1	−0.1
	B	−0.1	+0.2(2)	+0.5(2)
	C	+0.2	+0.1	+0.1(1)
	D	−0.3	+0.1(1)	+0.2
(c)	A1	+0.3	−0.2(1)	−0.8(1)
	A2	−0.1	−0.1	+0.2
	A3	−0.2	+0.3(1)	+0.6(1)
	B	−0.3(1)	−0.1	+0.1
	C	+0.2	+0.1	+0.8(2)
	D	−0.4(1)	−0.2(2)	+0.7(2)
(e)	A1	+0.6(2)	+0.2	+0.8(2)
	A2	−0.5(2)	−0.4(2)	−0.3(2)
	A3	−0.2	+0.2	−0.5
	B	+0.5	−0.1(1)	+0.4
	C	+0.3	+0.2(2)	+0.3
	D	+0.6(2)	−0.1	+0.1

Values used in stress calculation shown boxed, e.g.

0.2

	Position	M_x	M_y	M_z
Highest moment	A1	0.6	0.2	1.2
	A2	0.5	0.4	0.3
	A3	0.8	0.3	1.0
	B	0.8	0.2	0.5
	C	0.3	0.2	0.8
	D	0.6	0.2	0.7

	Position	M_x	M_y	M_z
Algebraic difference between higher(2) and 0.5 of lower	A1	0.75	0.3	1.6
	A2	0.6	0.45	0.4
	A3	0.9	0.45	1.3
	B	0.95	0.25	0.6
	C	0.2	0.25	0.75
	D	0.8	0.25	0.8

NOTE 1. Moment which, when combined with higher, gives the greatest algebraic difference.
NOTE 2. High (also the higher of combined moments).

F.7 Limits

F.7.1 General

In considering a sectionalized system, the limits applicable to one point in that system need not necessarily apply to another point.

To illustrate the derivation of limits and combined stresses, consider point B to the specimen configuration (see figure F.3).

F.7.2 The stress range limitation

F.7.2.1 All-cold to all-hot is to be the lower of **4.11.2**(a) (1) or (2).

Criterion (i): 0.9 x proof stress at 450 °C = 123.3 N/mm^2.

Criterion (ii): 0.9 x proof stress at room temperature = 229.5 N/mm^2.

Criterion (iii): 100 000 h mean stress to rupture at design temperature (450 °C) = 78 N/mm^2.

Criterion (ii) + criterion (iii) is less than criterion (ii) + criterion (i), therefore the limit for this mode (see table F.6 (1))

= 229.5 + 78 = 307.5 N/mm^2

NOTE. The limitations of **4.11.2**(a) (2) are more onerous than those of **4.11.2**(a) (1).

F.7.2.2 The stress range for modes other than all-hot should not exceed the all-hot limit (307.5 N/mm²) and in addition should not exceed the sum of 0.9 times the proof stress at the temperature at each end of the application cycle.

For this additional limit, it is necessary to identify the temperatures specific to the moments used in the sectionalized system calculation. In this case at point B (see table F.6(2)), the M_x moments used to apply to modes (b) and (c); the M_y moments apply to modes (a) and (b); the M_z moments apply to modes (b) and (c).

At point B mode (a) 450 °C
At point B mode (b) 250 °C
At point B mode (c) 450 °C

So that the temperature at each end of the cycle used in the calculation is 250 °C and 450 °C, respectively.

0.9 x proof stress at 450 °C = 123.3 N/mm²

0.9 x proof stress at 250 °C = 162.0 N/mm²

As 162.0 N/mm² + 123.3 N/mm² is less than the all-hot stress range limit (307.5 N/mm²), 285.3 N/mm² becomes the limit for sectionalized stress range other than all-hot.

F.7.3 All-hot stress limitation

The all-hot limit is defined by **4.11.2**(b) as mean stress to rupture in 100 000 h at design temperature (450 °C) = 78 N/mm².

The hot stress for modes other than all-hot should not exceed the all-hot limit, i.e. 78 N/mm².

NOTE. The hot stress calculation is necessary only where the stress range limiting criterion is determined by **4.11.2**(a) (2) as it is in this case.

F.7.4 Calculation of combined stress level at point B

F.7.4.1 Point B is on a bend. **4.11.4** defines stress evaluation on straights and bends.

From equation (28), the combined stress is

$$\sqrt{F^2 + 4f_s^2}$$

where

- F is the greater of f_T or f_L (in N/mm²);
- f_T is the transverse pressure stress + transverse bending stress (in N/mm²);
- f_L is the longitudinal pressure stress + longitudinal bending stress (in N/mm²);
- f_s is the torsional stress (in N/mm²).

At point B, from expression (29) the transverse pressure stress is

$$\frac{pd}{2t} + 0.5\,p = 11.07 \text{ N/mm}^2$$

where

- d = 101.6 mm;
- t = 6.3 mm;
- p = 1.3 N/mm².

At point B, from expression (32), the longitudinal pressure stress is

$$\frac{pd^2}{4t(d+t)} = 4.935 \text{ N/mm}^2$$

where terms are as in expression (29).

At point B, from expression (31), the transverse bending stress is

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

where

- r = 53.95 mm;
- I 3.1467 x 10⁶ mm⁴;
- M_i is the in-plane moment (in N·mm);
- M_o is the out-of-plane moment (in N·mm);
- F_{Ti} is the in-plane transverse stress intensification factor = 1.8 (see figure 4.11.1(3));
- F_{To} is the out-of-plane transverse stress intensification factor = 1.9 (see figure 4.11.1(5)).

Moments at point B

$M_t = M_z$ (see torsional stress)

$M_o = M_y$

$M_i = M_x$

F.7.4.2 Consider cold-to-hot stress range (mode (d) to (e)).

From table F.6(1)

$M_o = 0.3$

$M_i = 1.3$

Transverse bending stress for this mode therefore = 41.3 N/mm² and f_T = 41.3 + 11.07 = 52.37 N/mm².

At point B, from expression (34), the longitudinal stress is

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

where terms are as for expression (31) except that:

F_{Li} and F_{Lo} are the in-plane and out-of-plane stress intensification factors; and

F_{Li} = 1.6 with F_{Lo} = 1.7

so that the longitudinal bending stress for this mode = 36.73 N/mm² and f_L = 36.73 + 4.935 = 41.67 N/mm². As f_T is greater than f_L then $F = f_T$ = 52.37 N/mm².

At point B, from equation (35), the torsional stress is

$$\frac{M_t(d+2t)}{4I}$$

$M_t = M_z$ = 1.0 from moments table F.6(1).

Torsional stress for this mode therefore = 9.0 N/mm².

The combined stress at point B for cold-to-hot stress range mode (d) to (e) = 55.377 N/mm².

The stress range limit for this mode is 307.5 N/mm².

F.7.4.3 Considering the stress range at point B of the sectionalized system for modes other than all-hot, the moments are derived from table F.6(2). These are:

$M_t = 1.4$

$M_o = 0.6$

$M_i = 3.1$

Using these values in expressions (31), (34) and equation (35) and combining with stresses from expressions (29) and (32) to use in equation (28), the combined stress at point B, for stress range modes other than cold-to-hot = 108.9 N/mm^2. The stress range limit for this mode is 285.3 N/mm^2.

F.7.4.4 Considering hot stress at point B for all-hot mode (e), the moments are derived from moments table F.6(3).

NOTE. This value need not be calculated if **F.7.4.5** has to be calculated.

These are:

$M_t = M_z = 0.4$

$M_o = M_y = 0.1$

$M_i = M_x = 0.5$

Using these values in expressions (31), (34) and equation (35) and combining with pressure stresses from expressions (29) and (32) to use in equation (28), the combined hot stress at point B for all-hot mode (e) = 27.72 N/mm^2. The hot stress limit is 78 N/mm^2.

F.7.4.5 Considering the hot stress at point B of the sectionalized system for combined modes (a), (b), (c) and (e), the moments are derived from moments table F.6(4). These are:

$M_t = M_z = 0.6$

$M_o = M_y = 0.25$

$M_i = M_x = 0.95$

Using these values in expressions (31), (34 and equation (35) and combining with pressure stresses from expressions (29) and (32) to use in equation (28), the combined hot stress at point B for combined modes (a), (b), (c) and (e) = 42.9 N/mm^2. The hot stress limit is 78 N/mm^2.

F.8 Conclusion

Stress range and hot stress levels at point B are acceptable.

Appendix G. Flexibility flow chart

A flow chart showing a typical sequence of calculations for the flexibility analysis in **4.11** is given in figure G.1.

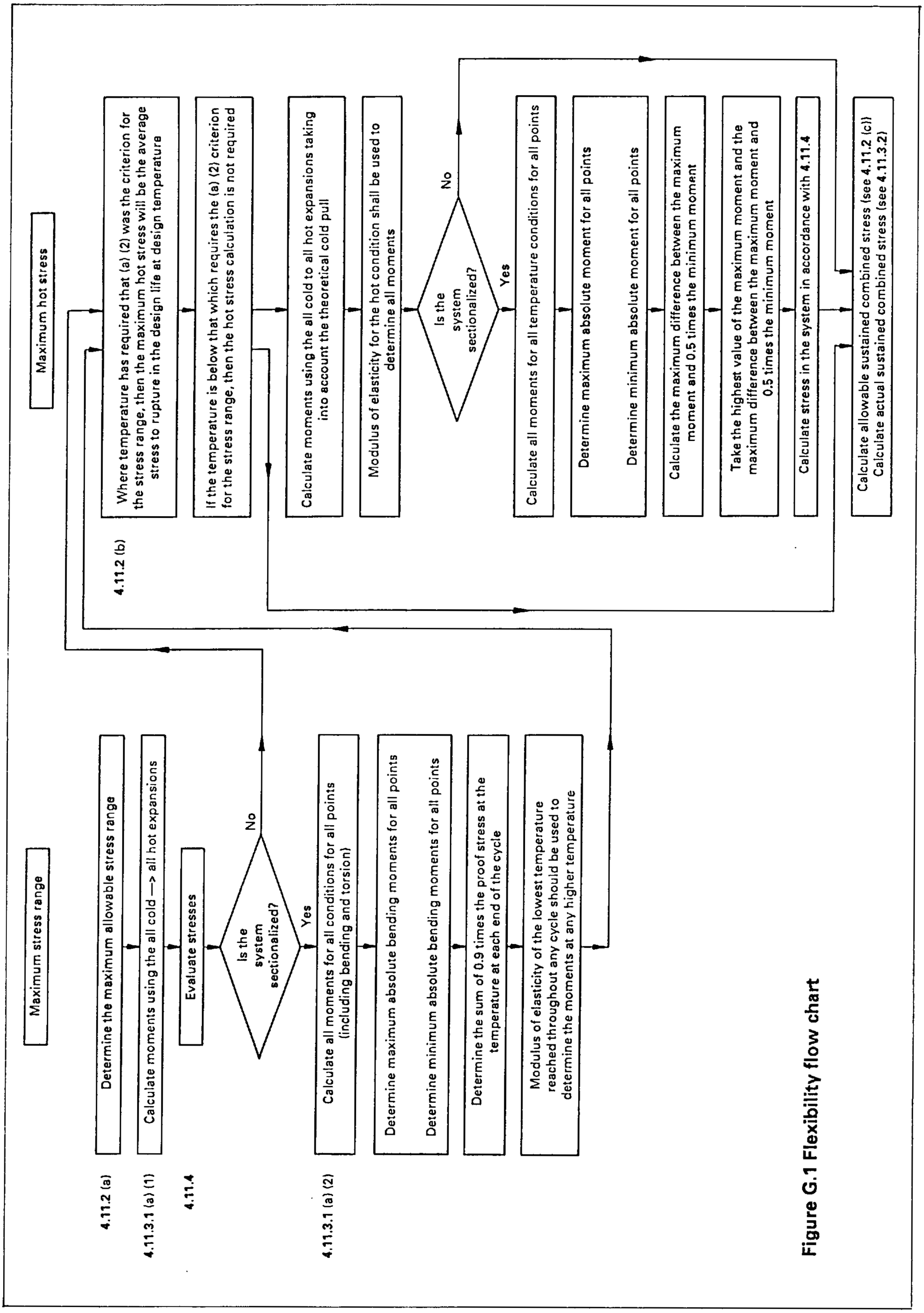


Figure G.1 Flexibility flow chart

Appendix H. Alternative method for evaluation of stresses in branches subjected to moment loads

H.1 Introduction

This appendix presents an alternative method of stress evaluation at branch junctions to that given in **4.11.5.** The method is subject to the limitations given in **H.3** and to modified acceptance criteria as given in **H.5**. The derivation of the method is described in the references listed in **H.6**. The method is based on the use of Effective Stress Factors (ESFs) defined as the ratio of the maximum Tresca stress intensity (i.e. the maximum principal stress difference) to the relevant nominal stress.

H.2 Notation

D_{m1}	Main pipe mean diameter (in mm)
D_{m2}	Branch pipe mean diameter (in mm)
d_1	Main pipe inside diameter (in mm)
D_1	Main pipe outside diameter (in mm)
f	Stress (in N/mm^2)
F	Effective stress factor (ESF)
F_A	ESF for case $t_2/t_1 = D_{m2}/D_{m1}$
F_B	ESF for case $t_2/t_1 = 1$
M	Bending or twisting moment (in N·mm)
P	Internal pressure (in N/mm^2)
t_1	Main pipe thickness (in mm)
t_2	Branch pipe thickness (in mm)
Z_1	Main pipe section modulus based on actual main pipe dimensions (see **H.4.3**)
Z_2	Branch pipe section modulus based on unreinforced branch thickness (see **H.4.3**)
1, 2	Subscripts – main or branch
p	Subscript – pressure
x, y, z	Space coordinates

H.3 Limitations of application

The method is limited in application to 90° branch junctions of the 'set on' full penetration welded or non protruding 'set in' full penetration welded types or to branch junctions of homogeneous construction with external profiles conforming to the minimum dimensions of figure 5.4 and within the following geometry ranges:

(a) $5 \leqslant D_{m1}/t_1 \leqslant 70$

(b) $D_{m2}/D_{m1} \leqslant t_2/t_1 \leqslant 1.0$

The method is not applicable to welded branch junctions incorporating compensating plates.

H.4 Method of calculation

H.4.1 A set of nine moments acting at the branch junction is produced by the flexibility analysis for the loadings under consideration (see figure H.4.1(1)). It is first necessary to interpret these nine moments in terms of the six moments 'cantilever model' shown in figure H.4.1(2). This is done as in the following example:

Consider the arbitrary balanced set of nine moments (any units) indicated in figure H.4.1(3).

These give the following two load sets having ignored signs:

M_{x2}	M_{y2}	M_{z2}	M_{x1}	M_{y1}	M_{z1}
9	11	21	5	8	19
9	11	21	14	3	2

The consequences of each of these two sets of six moments are considered after the applicable ESFs have been established.

H.4.2 ESFs for internal pressure loading and each of the six moments defined in figures H.4.1(2) are established as follows:

(a) Factor F_A for geometry $t_2/t_1 = D_{m2}/D_{m1}$ from figure H.4.2(1) (a) to (g).

(b) Factor F_B for geometry $t_2/t_1 = 1.0$ from figure H.4.2(2) (a) to (g).

NOTE. The polynomial equations for the curves in figures H.4.2(1) and H.4.2(2) given in table H.4.2.

For the actual value of t_2/t_1 the ESF is found by linear interpolation between the values obtained from (a) and (b) using the formula

$$F = F_A - (F_A - F_B)\left(\frac{t_2/t_1 - D_{m2}/D_{m1}}{1 - D_{m2}/D_{m1}}\right)$$

H.4.3 The stresses attributable to each of the seven load categories (pressure and six moments) are determined as follows:

$$f_p = F_p\, PD_{m1}/2t_1$$

$$f_{x1} = F_{x1}\frac{M_{x1}}{Z_1} \qquad f_{y1} = F_{y1}\frac{M_{y1}}{Z_1} \qquad f_{z1} = F_{z1}\frac{M_{z1}}{Z_1}$$

$$f_{x2} = F_{x2}\frac{M_{x2}}{Z_2} \qquad f_{y2} = F_{y2}\frac{M_{y2}}{Z_2} \qquad f_{z2} = F_{z2}\frac{M_{z2}}{Z_2}$$

The main pipe section modulus Z_1 is based on actual main pipe dimensions D_1 and d_1, i.e.

$$Z_1 = \frac{\pi}{32 D_1}\,(D_1^4 - d_1^4)$$

The section modulus for the branch pipe Z_2 is based on the actual branch mean diameter but with unreinforced thickness = $t_1(D_{m2}/D_{m1})$, i.e.

$$Z_2 = \frac{\pi\, D_{m2}^3}{4} \cdot \frac{t_1/D_{m1}[1 + (t_1/D_{m1})^2]}{[1 + (t_1/D_{m1})]}$$

H.4.4 Three stages of analysis of acceptability are involved.

(a) The first stage is to calculate the branch and main moment stress combinations. Thus, calculate

$f_{1c} = f_{x1} + f_{y1} + f_{z1}$

$f_{2c} = f_{x2} + f_{y2} + f_{z2}$

(b) The second stage involves combining branch and main stresses as follows

$f_{12} = f_{1c} + f_{2c}$

(c) The third stage involves combining the net moment stress f_{12} with the pressure stress f_p using circular interaction to give the total stress f_{tot}, i.e.

$f_{tot} = \sqrt{f_p^2 + f_{12}^2}$

The loading is acceptable provided the total stress f_{tot} due to just one of the moment load sets as illustrated at **H.4.1** combined with the pressure meets the appropriate acceptance criteria of **H.5**.

H.5 Acceptance criteria

The requirements of **4.11.2** and **4.11.3** as appropriate are applicable. The relaxation factor q as defined in **4.11.5.1** shall be used with f_{tot} in all hot stress evaluations.

H.6 References

1. MOFFAT, D.G., 'Experimental Stress Analysis of Four Fabricated Equal Diameter Branch Pipe Intersections Subjected to moment Loadings and the Implications on Branch Junction Design', Proc. I.Mech.E., Vol. 119, No. A4, 1985, pp. 261-284.

2. MOFFAT, D.G. and MISTRY, J., 'Interaction of External Moment Loads and Internal Pressure on a Variety of Branch Pipe Intersections', Proc. 6th Int. Conf. Pressure Vessel Technology, Beijing, 1988, Pergamon.

3. MOFFAT, D.G., MWENIFUMBO, J.A.M., XU, S.H. and MISTRY, J., 'Effective Stress Factors for Piping Branch Junctions due to Internal Pressure and External Moment Loads', I.Mech.E., J.Strain Analysis, Vol. 26, No. 2, 1991, pp. 85-101.

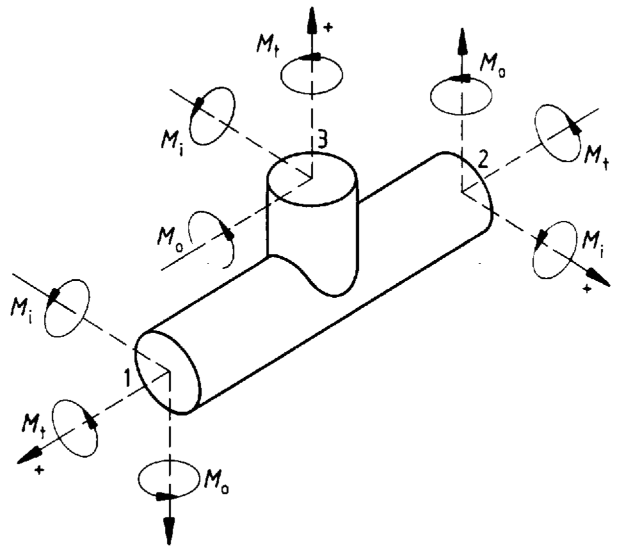


Figure H.4.1(1) Branch junction nine moment model

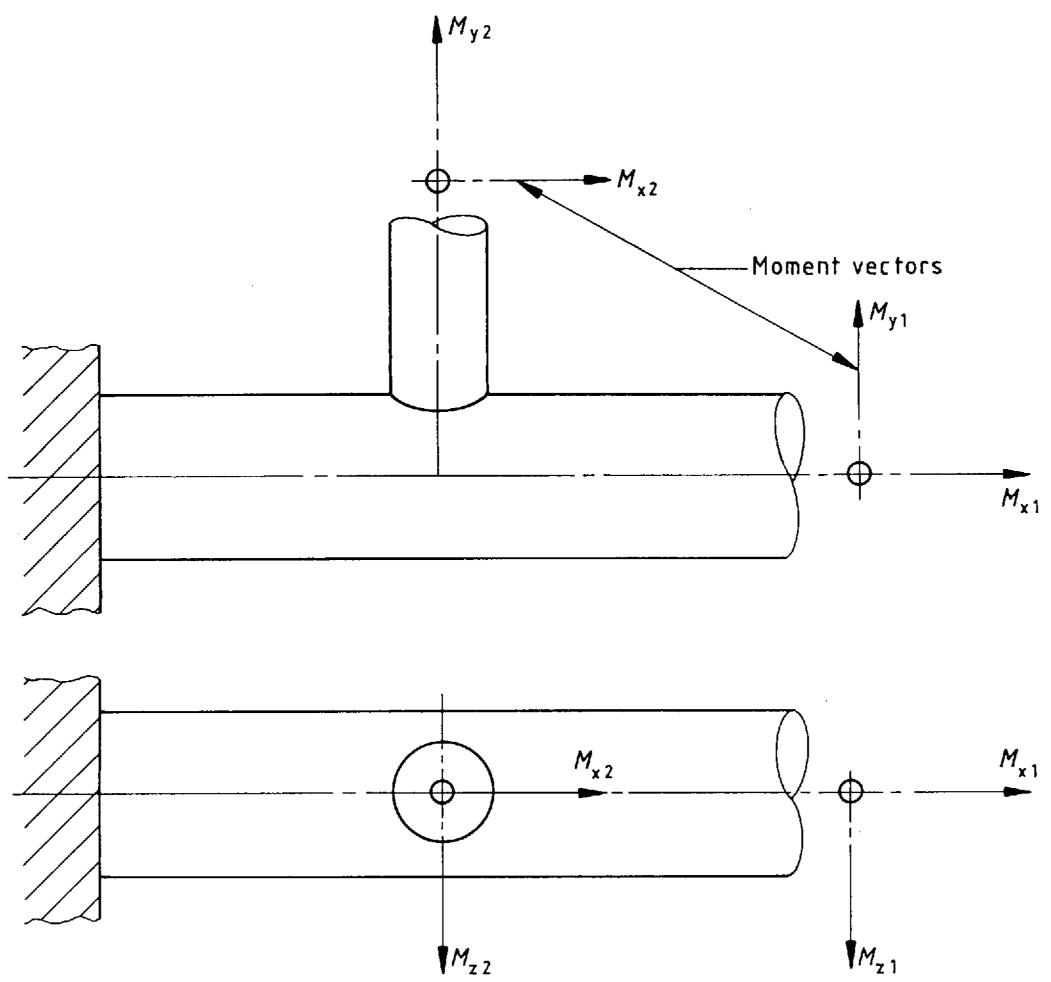


Figure H.4.1(2) Branch junction six moment cantilever model

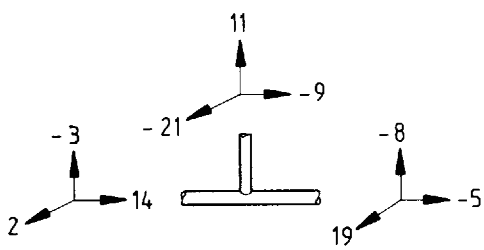
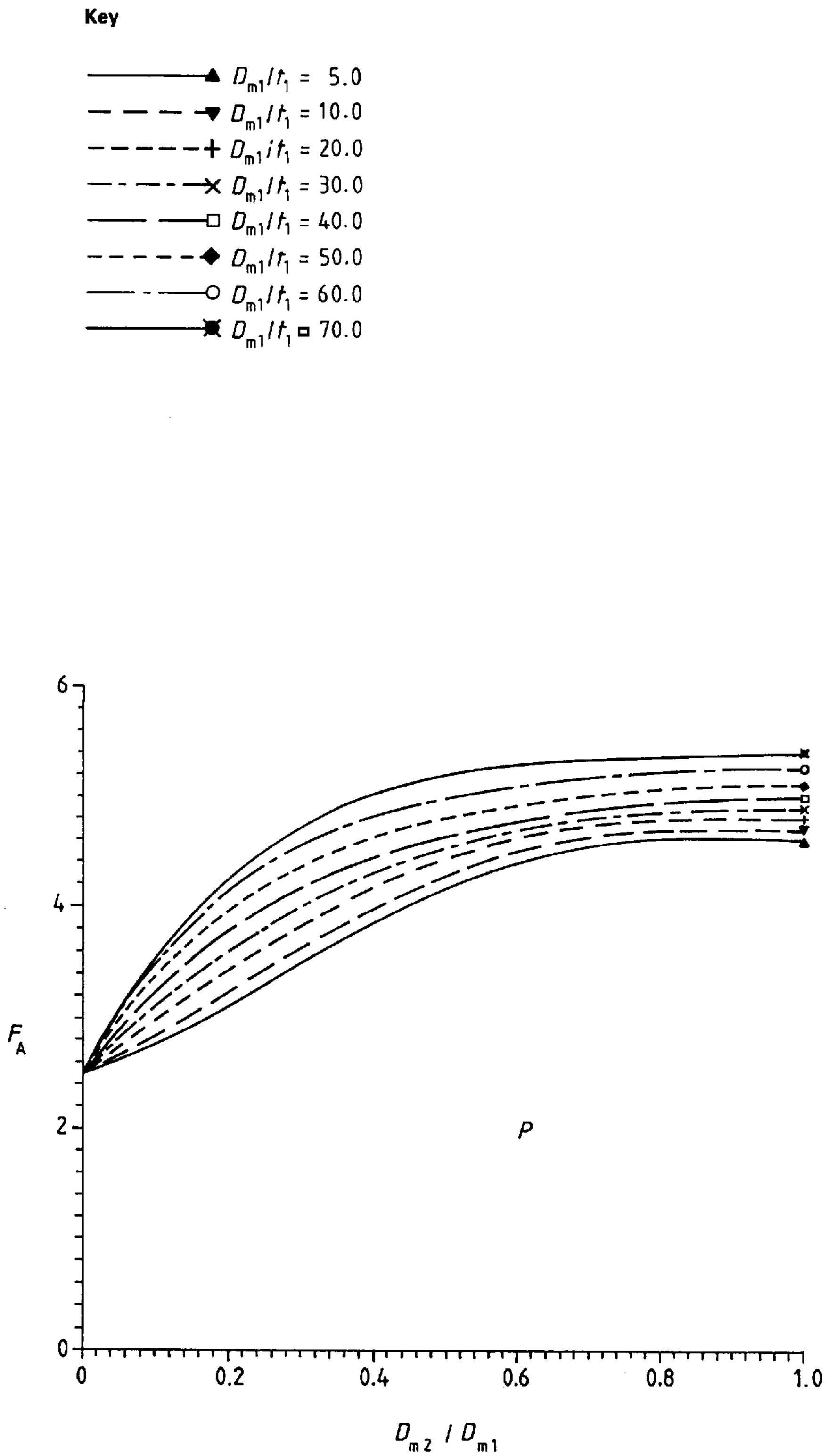


Figure H.4.1(3) Example of nine moment model



a)

Figure H.4.2(1) F_A **versus** $\frac{D_{m2}}{D_{m1}}$ **for** $\frac{D_{m2}}{D_{m1}} = \frac{t_2}{t_1}$

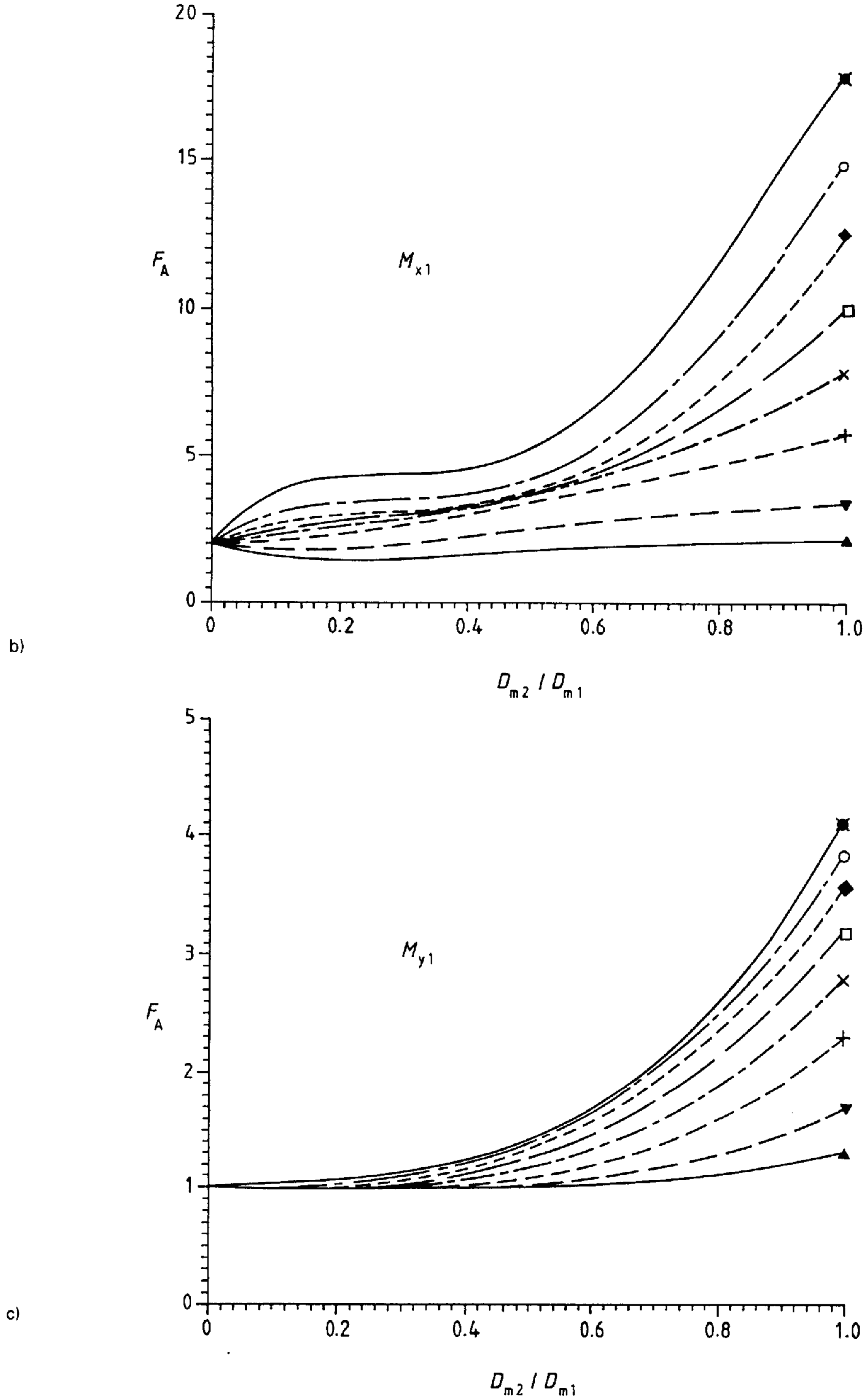
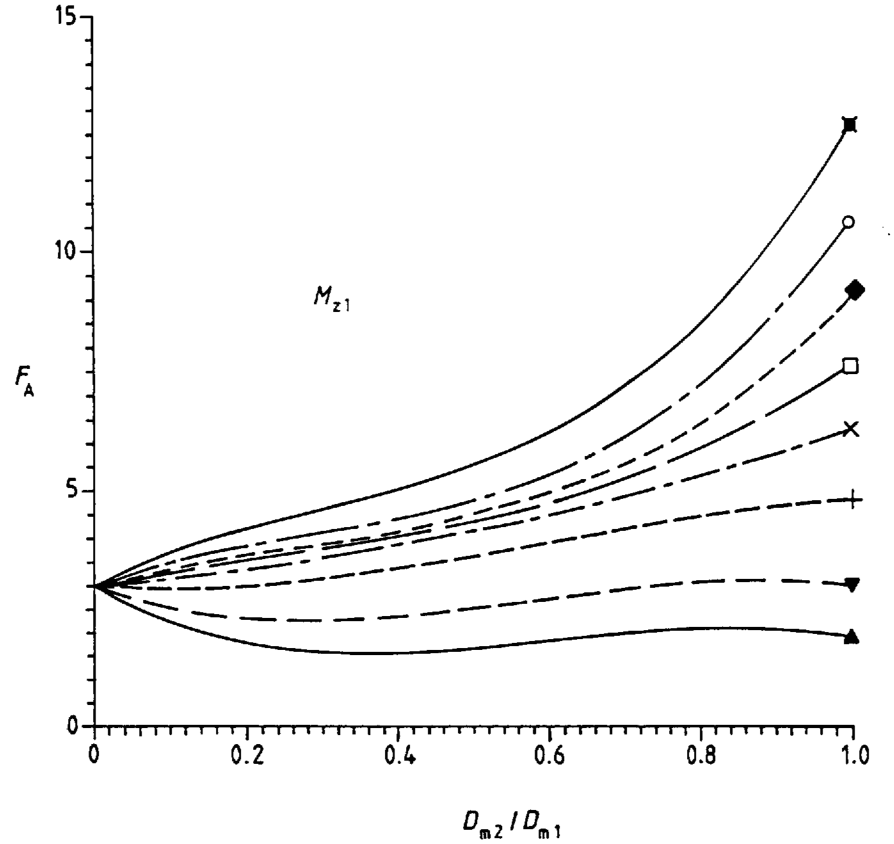
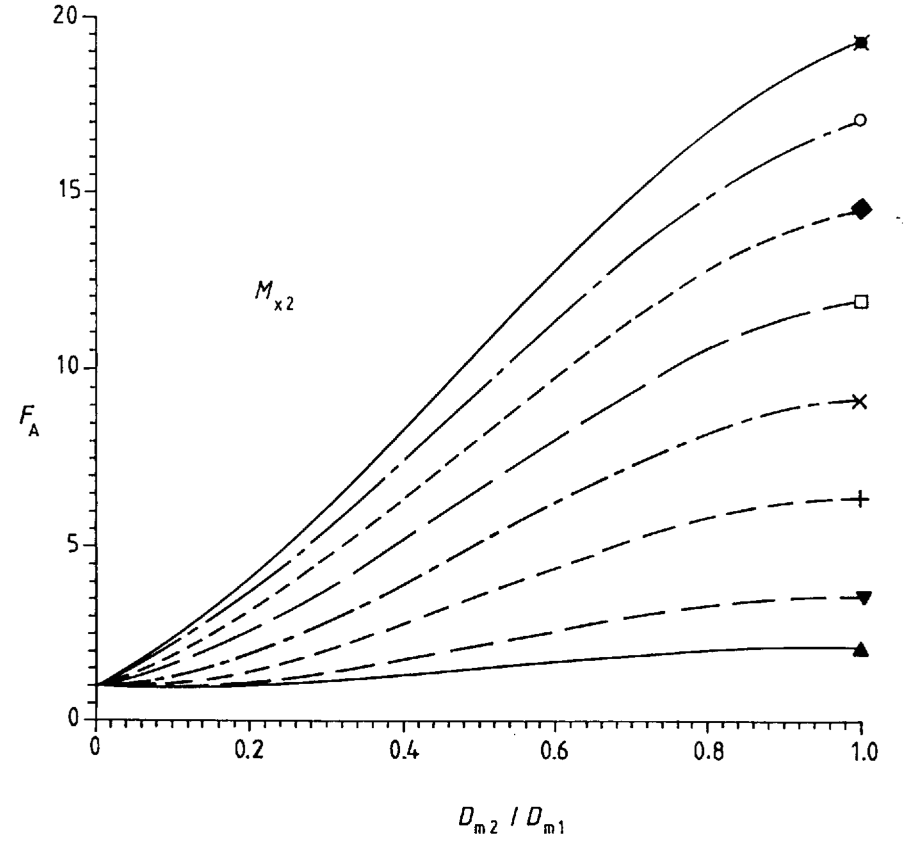


Figure H.4.2(1) *(continued)*

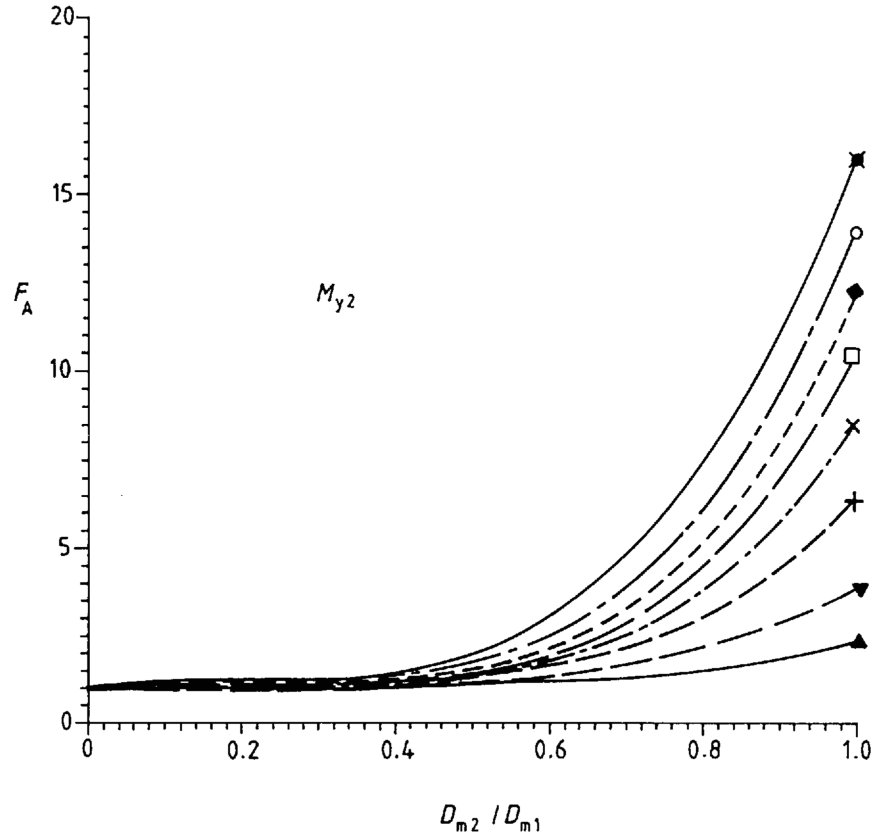


d)

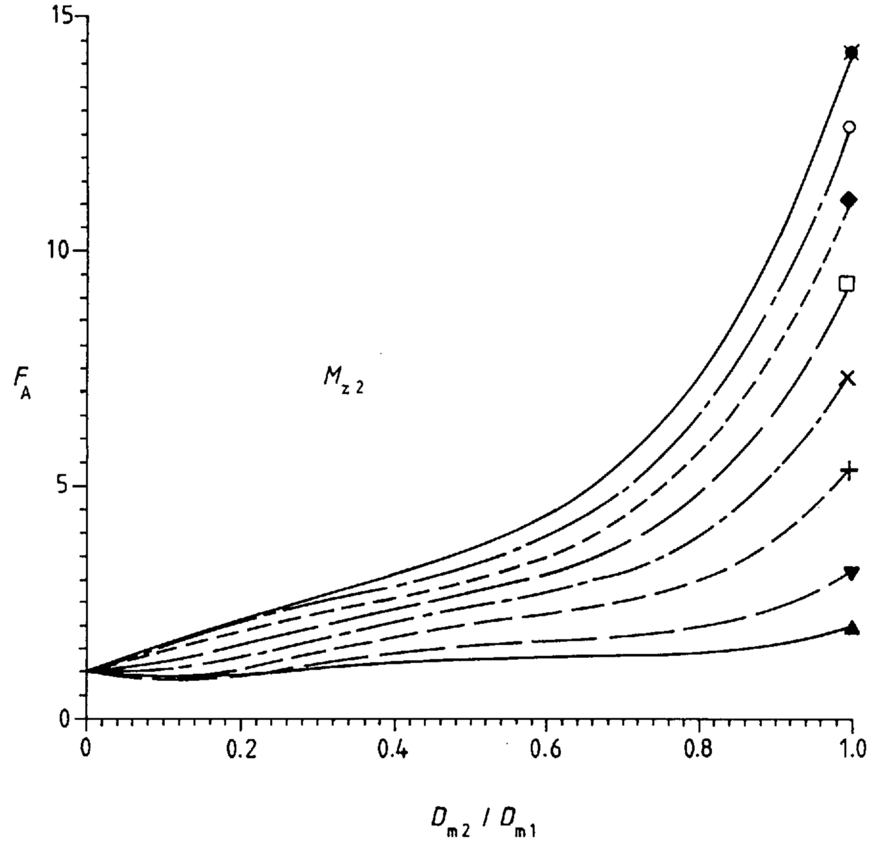


e)

Figure H.4.2(1) *(continued)*

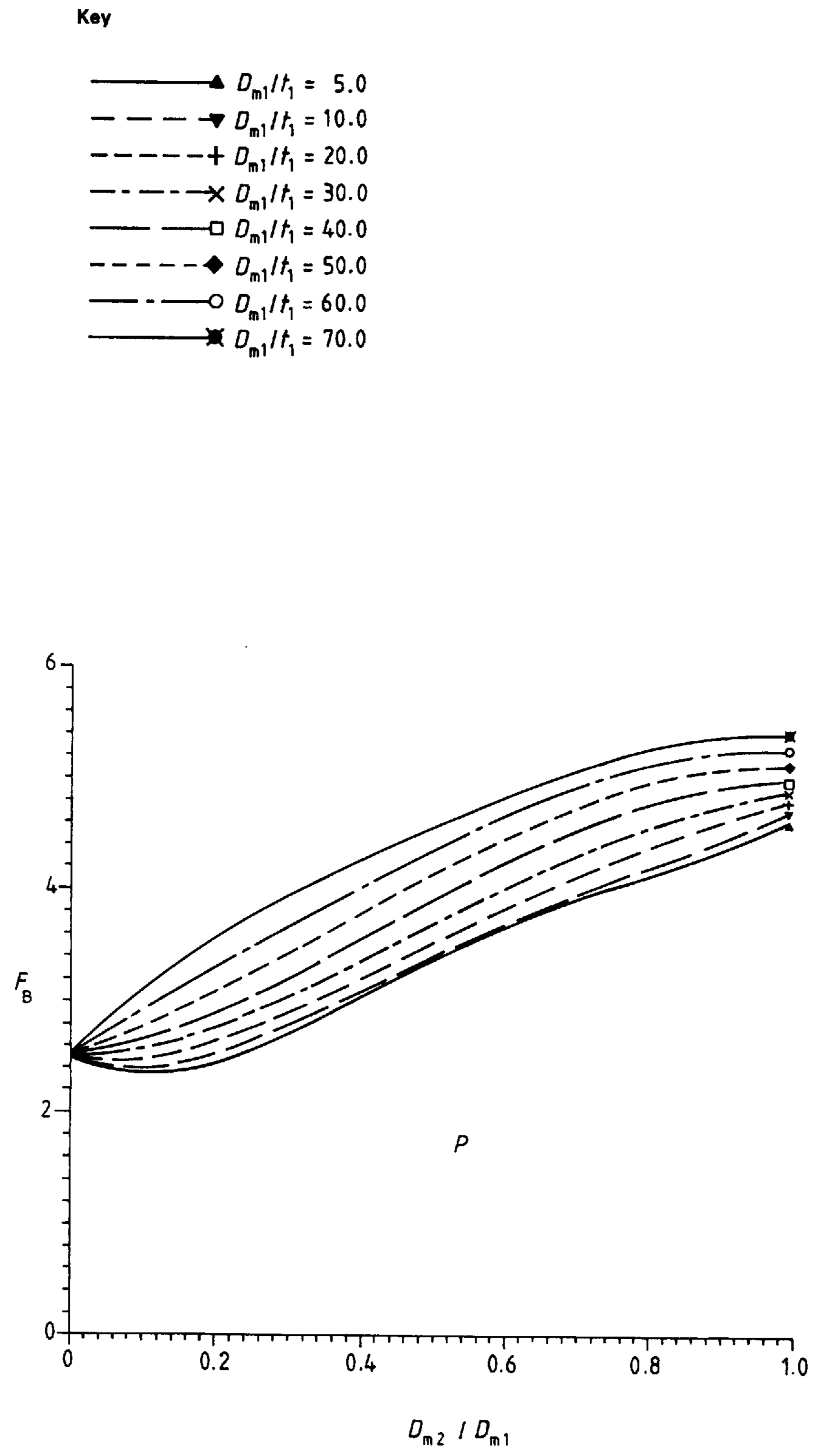


f)



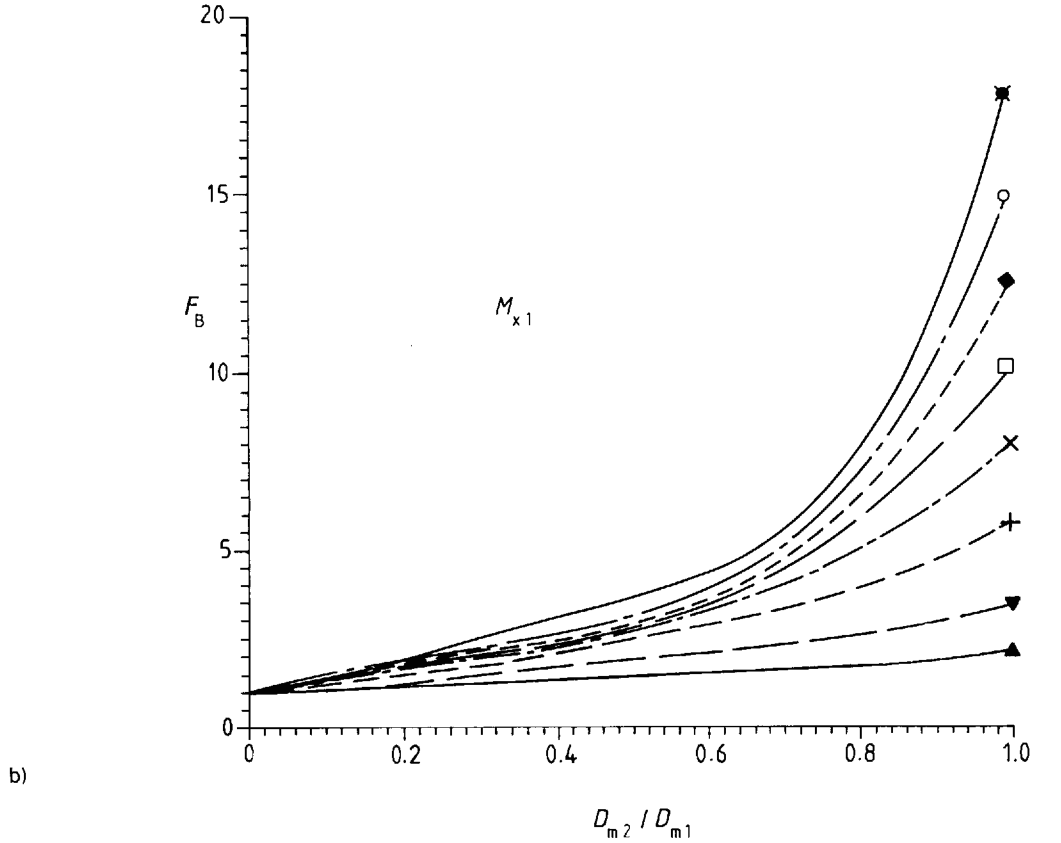
g)

Figure H.4.2(1) *(concluded)*



a)

Figure H.4.2(2) F_B **versus** $\frac{D_{m2}}{D_{m1}}$ **for** $\frac{t_2}{t_1} = 1$



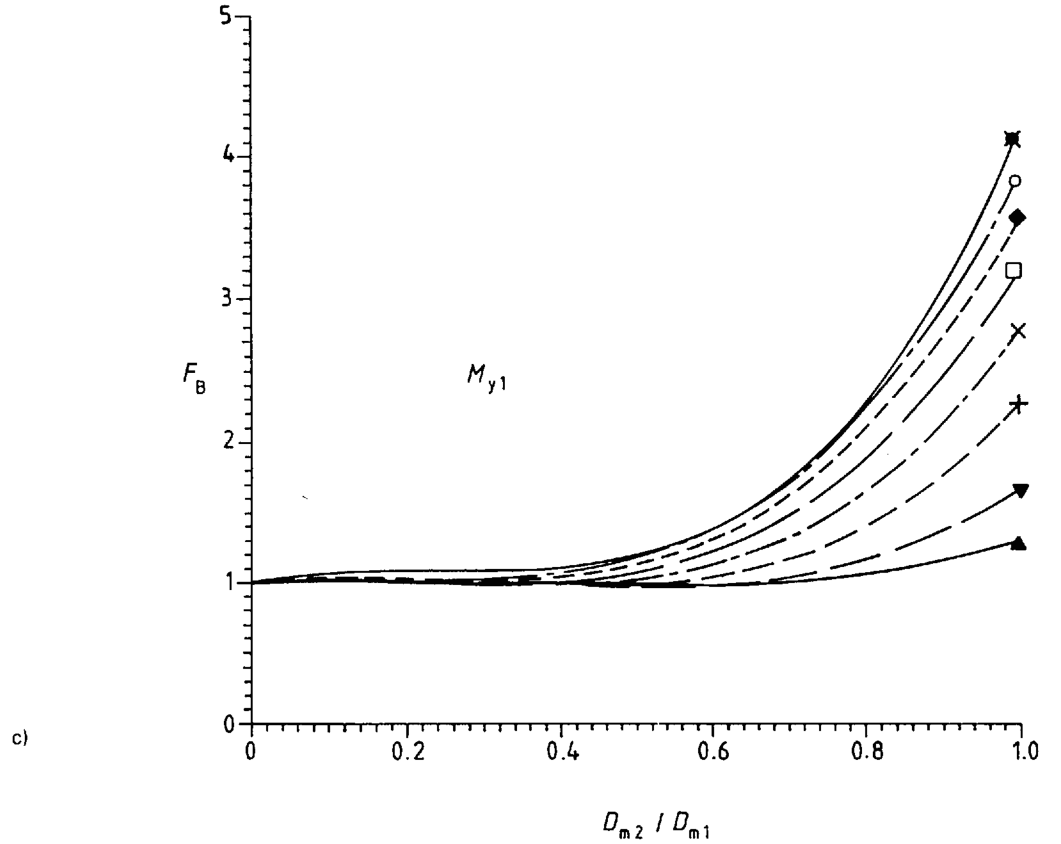
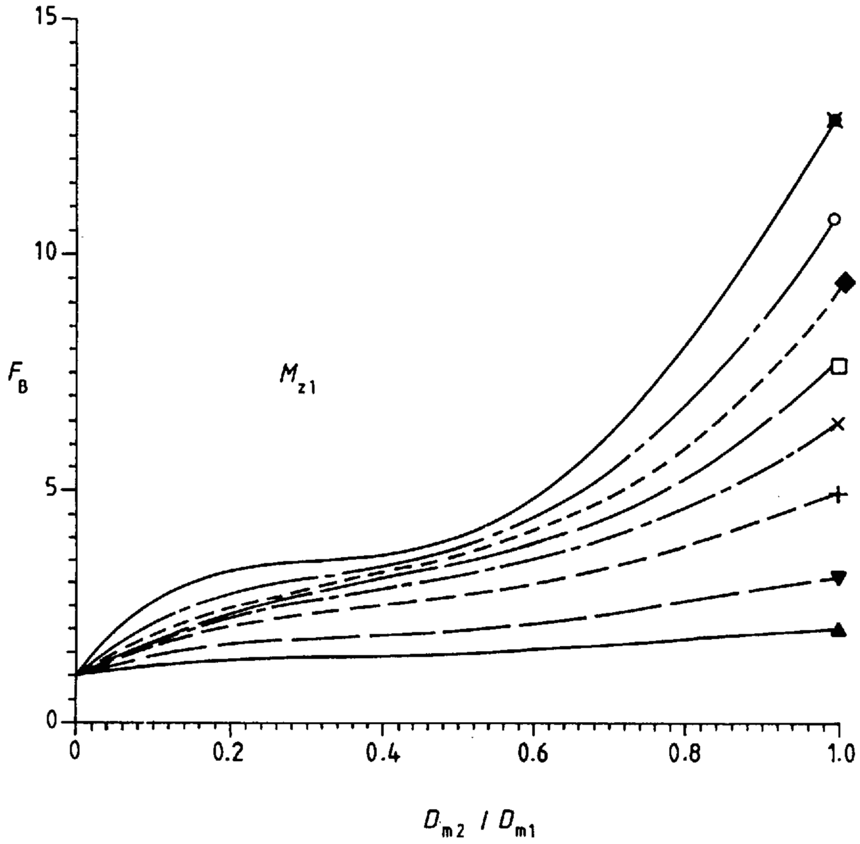
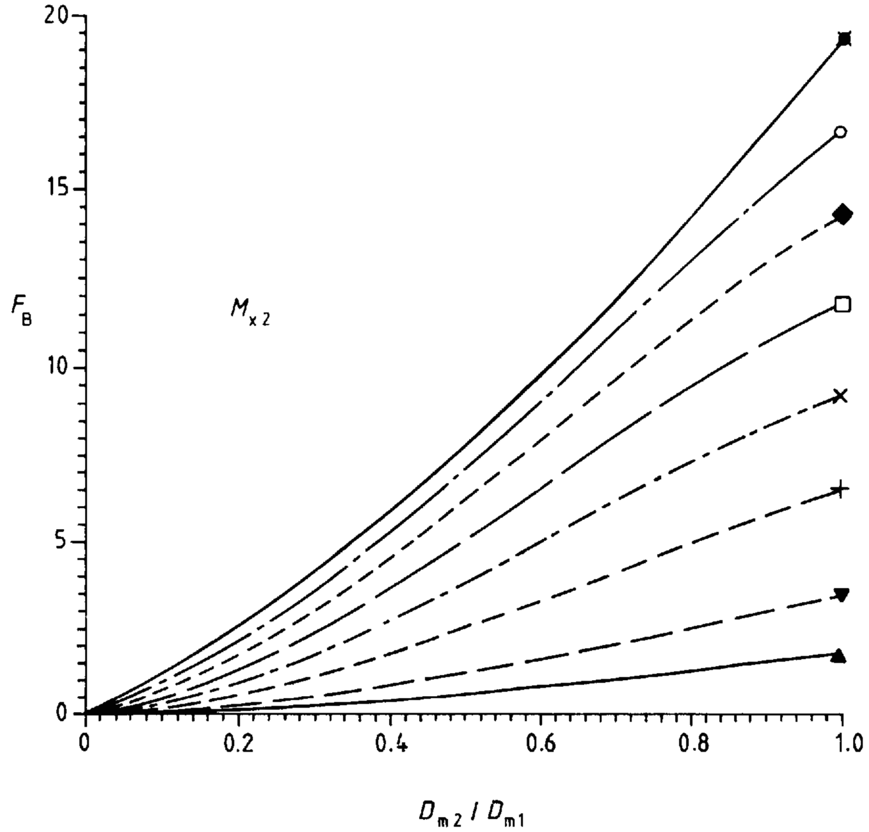


Figure H.4.2(2) *(continued)*



d)



e)

Figure H.4.2(2) *(continued)*

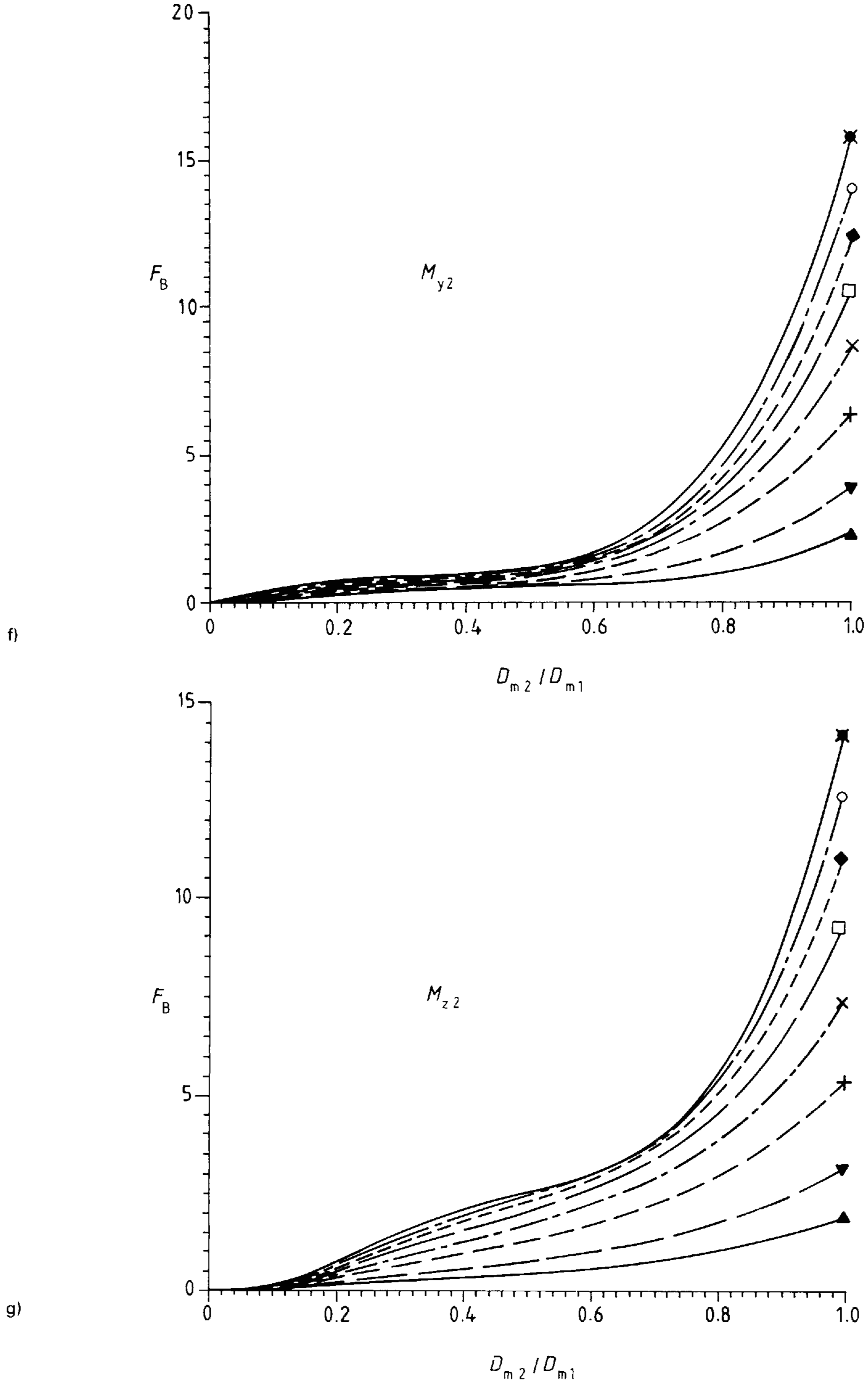


Figure H.4.2(2) *(concluded)*

Table H.4.2 Polynomial equations for figures H.4.2(1) and H.4.2(2)

Polynomials in the form ESF = $a_0 + a_1 x + a_2x^2 + a_3x^3 + a_4x^4$ where $x = D_{m2}/D_{m1}$

(a) $t_2/t_1 = D_{m2}/D_{m1}$ cases

Loading	D_{m1}/t_1	a_0	a_1	a_2	a_3	a_4
P Figure H.4.2(1) (a)	5	2.500E + 00	1.946E + 00	7.781E + 00	− 1.251E + 01	4.916E + 00
	10	2.500E + 00	2.758E + 00	6.337E + 00	− 1.190E + 01	5.024E + 00
	20	2.500E + 00	4.513E + 00	1.458E + 00	− 7.179E + 00	3.541E + 00
	30	2.500E + 00	6.445E + 00	− 5.121E + 00	5.450E − 01	5.510E − 01
	40	2.500E + 00	8.441E + 00	− 1.205E + 01	9.012E + 00	− 2.889E + 00
	50	2.500E + 00	1.027E + 01	− 1.779E + 01	1.576E + 01	− 5.603E + 00
	60	2.500E + 00	1.157E + 01	− 2.061E + 01	1.811E + 01	− 6.286E + 00
	70	2.500E + 00	1.186E + 01	− 1.859E + 01	1.315E + 01	− 3.503E + 00
M_{x1} Figure H.4.2(1) (b)	5	2.000E + 00	− 6.136E + 00	2.169E + 01	− 2.547E + 01	1.011E + 01
	10	2.000E + 00	− 3.188E + 00	1.579E + 01	− 1.763E + 01	6.494E + 00
	20	2.000E + 00	8.022E − 01	6.439E + 00	− 5.755E + 00	2.320E + 00
	30	2.000E + 00	3.358E + 00	− 2.458E + 00	5.656E + 00	− 5.880E − 01
	40	2.000E + 00	5.801E + 00	− 1.420E + 01	2.206E + 01	− 5.542E + 00
	50	2.000E + 00	9.454E + 00	− 3.212E + 01	4.893E + 01	− 1.587E + 01
	60	2.000E + 00	1.565E + 01	− 5.954E + 01	9.178E + 01	− 3.492E + 01
	70	2.000E + 00	2.570E + 01	− 9.982E + 01	1.561E + 02	− 6.603E + 01
M_{y1} Figure H.4.2(1) (c)	5	1.000E + 00	4.841E − 02	− 3.858E − 01	6.542E − 01	
	10	1.000E + 00	7.162E − 02	− 6.556E − 01	1.263E + 00	
	20	1.000E + 00	2.304E − 02	− 6.367E − 01	1.913E + 00	
	30	1.000E + 00	− 8.817E − 02	− 1.685E − 01	2.058E + 00	
	40	1.000E + 00	− 1.851E − 01	3.943E − 01	2.000E + 00	
	50	1.000E + 00	− 1.911E − 01	6.975E − 01	2.039E + 00	
	60	1.000E + 00	− 2.923E − 02	3.864E − 01	2.477E + 00	
	70	1.000E + 00	3.776E − 01	− 8.943E − 01	3.615E + 00	
M_{z1} Figure H.4.2(1) (d)	5	3.000E + 00	− 9.175E + 00	1.810E + 01	− 9.995E + 00	
	10	3.000E + 00	− 5.797E + 00	1.374E + 01	− 7.905E + 00	
	20	3.000E + 00	− 1.028E + 00	6.557E + 00	− 3.642E + 00	
	30	3.000E + 00	1.744E + 00	1.010E + 00	6.347E − 01	
	40	3.000E + 00	3.302E + 00	− 3.380E + 00	4.810E + 00	
	50	3.000E + 00	4.429E + 00	− 7.095E + 00	8.771E + 00	
	60	3.000E + 00	5.909E + 00	− 1.062E + 01	1.241E + 01	
	70	3.000E + 00	8.525E + 00	− 1.443E + 01	1.560E + 01	
M_{x2} Figure H.4.2(1) (e)	5	1.000E + 00	− 9.081E − 01	5.565E + 00	− 3.514E + 00	
	10	1.000E + 00	− 1.460E + 00	1.110E + 01	− 7.073E + 00	
	20	1.000E + 00	− 9.492E − 01	1.819E + 01	− 1.183E + 01	
	30	1.000E + 00	1.122E + 00	2.129E + 01	− 1.422E + 01	
	40	1.000E + 00	4.044E + 00	2.201E + 01	− 1.514E + 01	
	50	1.000E + 00	7.105E + 00	2.194E + 01	− 1.552E + 01	
	60	1.000E + 00	9.597E + 00	2.268E + 01	− 1.628E + 01	
	70	1.000E + 00	1.081E + 01	2.584E + 01	− 1.833E + 01	
M_{y2} Figure H.4.2(1) (f)	5	1.000E + 00	− 9.276E − 01	4.106E + 00	− 5.825E + 00	3.984E + 00
	10	1.000E + 00	− 1.639E + 00	7.462E + 00	− 1.109E + 01	8.126E + 00
	20	1.000E + 00	− 1.845E + 00	9.221E + 00	− 1.571E + 01	1.379E + 01
	30	1.000E + 00	− 9.008E − 01	6.045E + 00	− 1.378E + 01	1.625E + 01
	40	1.000E + 00	6.169E − 01	− 2.456E − 02	− 6.977E + 00	1.588E + 01
	50	1.000E + 00	2.139E + 00	− 6.986E + 00	3.077E + 00	1.301E + 01
	60	1.000E + 00	3.095E + 00	− 1.282E + 01	1.474E + 01	8.005E + 00
	70	1.000E + 00	2.907E + 00	− 1.549E + 01	2.634E + 01	1.231E + 00
M_{z2} Figure H.4.2(1) (g)	5	1.000E + 00	− 1.888E + 00	1.181E + 01	− 1.895E + 01	1.002E + 01
	10	1.000E + 00	− 3.352E + 00	2.203E + 01	− 3.588E + 01	1.938E + 01
	20	1.000E + 00	− 3.841E + 00	3.006E + 01	− 5.113E + 01	2.931E + 01
	30	1.000E + 00	− 2.031E + 00	2.621E + 01	− 4.840E + 01	3.065E + 01
	40	1.000E + 00	9.480E − 01	1.603E + 01	− 3.575E + 01	2.709E + 01
	50	1.000E + 00	3.940E + 00	5.203E + 00	− 2.150E + 01	2.243E + 01
	60	1.000E + 00	5.817E + 00	− 7.491E − 01	− 1.369E + 01	2.033E + 01
	70	1.000E + 00	5.426E + 00	3.842E + 00	− 2.060E + 01	2.459E + 01

Table H.4.2 *(concluded)*

(b) t_2/t_1 = 1 cases

Loading	D_{m1}/t_1	a_0	a_1	a_2	a_3	a_4
P Figure H.4.2(2) (a)	5	2.500E + 00	− 3.037E + 00	1.848E + 01	− 2.255E + 01	9.249E + 00
	10	2.500E + 00	− 2.173E + 00	1.499E + 01	− 1.778E + 01	7.181E + 00
	20	2.500E + 00	− 1.017E + 00	1.088E + 01	− 1.179E + 01	4.254E + 00
	30	2.500E + 00	− 1.510E − 01	8.684E + 00	− 8.532E + 00	2.417E + 00
	40	2.500E + 00	8.533E − 01	6.619E + 00	− 6.068E + 00	1.107E + 00
	50	2.500E + 00	2.278E + 00	3.372E + 00	− 2.766E + 00	− 2.504E − 01
	60	2.500E + 00	4.249E + 00	− 1.845E + 00	2.566E + 00	− 2.190E + 00
	70	2.500E + 00	6.745E + 00	− 9.344E + 00	1.077E + 01	− 5.246E + 00
M_{x1} Figure H.4.2(2) (b)	5	1.000E + 00	− 3.210E − 01	6.187E + 00	− 9.997E + 00	5.321E + 00
	10	1.000E + 00	− 1.069E − 01	9.197E + 00	− 1.444E + 01	7.820E + 00
	20	1.000E + 00	1.400E + 00	6.423E + 00	− 9.736E + 00	6.720E + 00
	30	1.000E + 00	3.575E + 00	− 2.525E + 00	3.791E + 00	2.131E + 00
	40	1.000E + 00	5.491E + 00	− 1.098E + 01	1.496E + 01	− 3.638E − 01
	50	1.000E + 00	6.221E + 00	− 1.225E + 01	1.258E + 01	4.827E + 00
	60	1.000E + 00	4.842E + 00	3.130E − 01	− 1.450E + 01	2.327E + 01
	70	1.000E + 00	4.345E − 01	3.334E + 01	− 7.739E + 01	6.051E + 01
M_{y1} Figure H.4.2(2) (c)	5	1.000E + 00	2.910E − 01	− 1.321E + 00	1.340E + 00	
	10	1.000E + 00	5.315E − 01	− 2.482E + 00	2.615E + 00	
	20	1.000E + 00	6.908E − 01	− 3.497E + 00	4.087E + 00	
	30	1.000E + 00	5.767E − 01	− 3.348E + 00	4.559E + 00	
	40	1.000E + 00	3.762E − 01	− 2.728E + 00	4.557E + 00	
	50	1.000E + 00	2.762E − 01	− 2.329E + 00	4.607E + 00	
	60	1.000E + 00	4.634E − 01	− 2.843E + 00	5.234E + 00	
	70	1.000E + 00	1.125E + 00	− 4.962E + 00	6.964E + 00	
M_{z1} Figure H.4.2(2) (d)	5	1.000E + 00	3.151E + 00	− 9.702E + 00	1.348E + 01	− 5.940E + 00
	10	1.000E + 00	5.984E + 00	− 1.746E + 01	2.373E + 01	− 1.016E + 01
	20	1.000E + 00	8.795E + 00	− 2.209E + 01	2.788E + 01	− 1.066E + 01
	30	1.000E + 00	9.257E + 00	− 1.858E + 01	2.015E + 01	− 5.411E + 00
	40	1.000E + 00	9.124E + 00	− 1.465E + 01	1.249E + 01	− 2.089E − 01
	50	1.000E + 00	1.014E + 01	− 1.793E + 01	1.673E + 01	− 8.115E − 01
	60	1.000E + 00	1.405E + 01	− 3.613E + 01	4.482E + 01	− 1.302E + 01
	70	1.000E + 00	2.262E + 01	− 7.693E + 01	1.087E + 02	− 4.264E + 01
M_{x2} Figure H.4.2(2) (e)	5	0.	2.113E − 01	2.280E + 00	− 6.961E − 01	
	10	0.	4.077E − 01	5.007E + 00	− 1.941E + 00	
	20	0.	9.063E − 01	1.089E + 01	− 5.251E + 00	
	30	0.	1.688E + 00	1.632E + 01	− 8.709E + 00	
	40	0.	2.923E + 00	2.012E + 01	− 1.119E + 01	
	50	0.	4.780E + 00	2.107E + 01	− 1.155E + 01	
	60	0.	7.431E + 00	1.797E + 01	− 8.672E + 00	
	70	0.	1.104E + 01	9.614E + 01	− 1.421E + 00	
M_{y2} Figure H.4.2(2) (f)	5	0.	− 1.261E − 01	9.783E + 00	− 2.171E + 01	1.455E + 01
	10	0.	1.166E + 00	1.834E + 00	− 7.429E + 00	8.331E + 00
	20	0.	2.660E + 00	− 5.730E + 00	4.207E + 00	5.263E + 00
	30	0.	3.114E + 00	− 5.314E + 00	− 4.101E − 01	1.118E + 01
	40	0.	3.017E + 00	− 6.520E − 01	− 1.376E + 01	2.189E + 01
	50	0.	2.865E + 00	4.492E + 00	− 2.826E + 01	3.318E + 01
	60	0.	3.152E + 00	6.356E + 00	− 3.634E + 01	4.084E + 01
	70	0.	4.376E + 00	1.162E + 00	− 3.041E + 01	4.065E + 01
M_{z2} Figure H.4.2(2) (g)	5	0.	7.386E − 01	7.897E − 01	− 2.102E + 00	2.507E + 00
	10	0.	6.534E − 01	3.594E + 00	− 6.215E + 00	5.122E + 00
	20	0.	4.078E − 01	9.576E + 00	− 1.622E + 01	1.164E + 01
	30	0.	4.273E − 02	1.622E + 01	− 2.886E + 01	2.004E + 01
	40	0.	− 4.579E − 01	2.368E + 01	− 4.439E + 01	3.045E + 01
	50	0.	− 1.114E + 00	3.214E + 01	− 6.307E + 01	4.306E + 01
	60	0.	− 1.944E + 00	4.177E + 01	− 8.520E + 01	5.804E + 01
	70	0.	− 2.966E + 00	5.275E + 01	− 1.110E + 02	7.554E + 01

Appendix J. Branch connections: design by analysis

J.1 General. This appendix gives guidance for the derivation of stress systems from the application of loads on branches whose pressure design is covered by **4.8**.

The appendix may be used at the discretion of the designer when the limits of **4.11.2** following the procedure given in **4.11.5** are exceeded.

J.2 Acceptability criteria. The requirements for the acceptability of a 'design by analysis' are given as (a) to (d) below.

An acceptable design assessment may be achieved by use of:

(a) a recognized finite element code provided that the modelling and solution procedures adhere to the guide-lines set out by the National Agency for Finite Element Methods and Standards (NAFEMS);

or

(b) a database of known stress intensities provided the geometric parameters lie within the range of applicability;

(c) the stress intensities obtained from the design by analysis should not exceed the acceptance criteria given by **4.11.2** for the appropriate load combinations considered;

(d) the relaxation factor *q* given by **4.11.5.1** shall be used in all hot stress evaluations.

BS 806 : 1993 Specification for design and construction of ferrous piping installations for and in connection with land boilers

Enquiry Cases–Introduction

In accordance with the provisions of **1.2**, the publication of Enquiry Cases will be notified in *BSI News* and will be made available for inclusion in the ring-binder in a separate section following the text of the specification and the appendices.

The table below is for recording cases as they are published and included in the binder, and for noting their subsequent routing.

In general, cases will be extant, as adjuncts to the standard and open to public comment, until the text of the standard is amended to incorporate the substance of particular cases. This will be done in the course of the normal updating procedure and each case so dealt with will be recorded on the final page of the relevant amendment.

When a new edition of the standard is published, embracing all previously issued amendments, the relevant enquiry cases will be removed from the list and only those remaining extant, as described above, will be referred to. Consequently, the numerical sequence of enquiry case numbers in the first column will not be continuous because of these omissions.

Enquiry Case No.	Date of publication	Subject of the Enquiry Case	Subsequent Enquiry Case routing (e.g. incorporated into BS 806)	Date of subsequent action
806/1	July 1986	Use of materials complying with API 5L, ASTM A 106, A 182, A 312 and A 335 (supersedes Enquiry Case No. BS 806/A: September 1982 to BS 806 : 1975 and extended to include austenitic steels)		Revised June 1987 January 1991 December 1992
806/2	November 1986	Occasional loads		Revised January 1989 July 1991
806/3	August 1987	Designing pipework in nuclear power stations to withstand safe shutdown earthquake (SSE)		Revised July 1991
806/4	October 1989	EFW Alloy pipe for wet steam applications		
806/5	March 1990	Single non-repeated anchor/restraint movements		Revised January 1991
806/6	January 1991	Use of buttwelding pipe fittings		
806/7	July 1991	Testing of pipe bends		

BSI STANDARDS

Enquiry Case 806/1 : July 1986
to BS 806 : 1986
Issue 4, December 1992

Enquiry Case BS 806/1

Use of materials complying with API 5L, ASTM A 106, A 182, A 312 and A 335

Enquiry

In order to deal with instances where piping materials complying with BS 3602, BS 3604, BS 3605 and BS 1503 are not available for use in piping systems complying with BS 806 and where materials certified as complying with the following API and ASTM standards are available, can they be used as acceptable alternatives?

API 5L	Specification for line pipe
ASTM A 106	Specification for seamless carbon steel pipe for high-temperature service
ASTM A 182	Specification for forged or rolled alloy steel pipe flanges, forged fittings and valves for high-temperature service
ASTM A 312	Specification for seamless and welded austenitic stainless steel pipe
ASTM A 335	Specification for seamless ferritic alloy steel for high-temperature service

Reply

1. For steels complying with API 5L, ASTM A 106 and ASTM A 335

Based on the editions current in 1984, steels complying with API 5L Grade B and ASTM A 106 Grade B, with maximum carbon content of 0.25 % *(m/m)* in both cases, and ASTM A 335 grades P11, P12 and P22 are acceptable.

The design stresses given in table 1 of this Enquiry Case may be used without the verification of $R_{e(T)}$ values, provided that the heat treatment of completed pipes is as given in table 2 of this Enquiry Case.

In connection with the hydraulic pressure testing of pipework, the value of R_e, the specified minimum yield stress, should be taken as 241 N/mm^2 for carbon steels and 207 N/mm^2 for alloy steels.

In connection with flexibility analysis, the following values should be used:

(a) the expansion allowances given for carbon and low alloy steels in table 4.10 of BS 806 : 1990;

(b) the moduli of elasticity given in table 4.11.1 of BS 806 : 1990;

(c) the 0.2 % proof stresses given in table 3 of this Enquiry Case;

(d) the average rupture stresses given in tables 4 to 6 of this Enquiry Case.

Table 1. Design stress values

Material	Tube 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	410	420	430	440	450	460	470	480	490	500	510	520	530	540	550	560	570	580		
Carbon	API ASTM	5L Grade B A 106 B	160	147	135	122	110	99	91	85	85	84	79	69	60	52	44	36											100 000	1
												83	74	65	56	48	40	32											150 000	
												80	71	62	53	45	37	28											200 000	
												78	68	59	51	42	35	26											250 000	
Alloy	ASTM	A 335 P11 A335 P12	138	133	128	121	115	98	86	84					83					80	78	76	62	52	42	33	27		100 000	1
																					78	67	55	44	35	29	24		150 000	
																					76	61	49	40	32	26	22		200 000	
																					70	57	45	37	30	25	20		250 000	
Alloy	ASTM	A 335 P22 (N+T)	138	120	102	97	91	89	86	83					77					71	70	69	68	61	53	45	39	34	100 000	1, 2, 3, 4
																						69	63	56	48	42	36	31	150 000	
																						68	59	52	45	38	33	28	200 000	
																						65	57	49	42	36	32	27	250 000	
Alloy	ASTM	A 335 P22 (Annealed)	138	102	65	60	56	53	51	48					46					44					39	38	37	34	100 000	1, 3, 4
																										38	36	31	150 000	
																										38	33	28	200 000	
																										36	32	27	250 000	

NOTE 1. The general notes to table 3.2 of BS 806 : 1990 apply.

NOTE 2. If test certificates certifying normalizing within the range 900 °C to 960 °C and tempering within the range 675 °C to 750 °C are not available, it is essential that the design stress values for the annealed steel be used.

NOTE 3. At temperatures at or above 580 °C the effect of scaling becomes significant and it is essential that due allowance be made for this.

NOTE 4. The time-dependent values are lower than those established by experience and established values up to 10 % higher may be permitted subject to continued fitness for service reviews being instituted at two-thirds of the design lifetime (see **2.8** of BS 806 : 1990) and by agreement between the purchaser and the manufacturer, (see **1.4.2.2**(c) of BS 806 : 1990), providing the resulting value does not exceed the lowest time-independent stress value given.

Table 2. Heat treatment of completed pipes

Material	Specification	Heat treatment temperature		
		Normalized	Tempered	Annealed
		°C	°C	°C
Carbon steel	Grade B of API 5L; Grade B of ASTM A 106	880 to 940	–	–
1 Cr 1/2 Mo	Grade P12 of ASTM A 335	900 to 960	650 to 720	–
1 1/4 Cr 1/2 Mo	Grade P11 of ASTM A 335	900 to 960	650 to 720	–
2 1/4 Cr 1 Mo	Grade P22 (N+T) of ASTM A 335	900 to 960	675 to 750	–
2 1/4 Cr 1 Mo	Grade P22 (Annealed) of ASTM A 335	–	–	900 to 960

NOTE. Read in conjunction with **5.2.1**.

Table 3. 0.2 % proof stress values

Steel grade	Values of 0.2 % proof stress (N/mm^2) at temperatures (°C) not exceeding										
	150	200	250	300	350	400	450	500	550	560	580
API 5L Grade B; ASTM A 106 Grade B	203	183	165	149	136	128	123				
ASTM A 335 P11, P12	205	194	184	157	138	135	133	128	112		
ASTM A 335 P22 A	104	96	90	85	82	77	74	70	62	60	56
ASTM A 335 P22 (N+T)	163	155	146	142	138	133	123	114	106		

Table 4. Average rupture stress values for steels API 5L Grade B and ASTM A 106 Grade B

Temperature °C	Values of average rupture stress (N/mm^2) for lifetime (h)			
	100 000	150 000	200 000	250 000
380	171	164	159	155
390	155	149	144	140
400	141	134	130	126
410	127	121	116	113
420	114	108	104	101
430	102	96	92	89
440	90	84	80	77
450	78	73	69	66
460	67	62	58	55
470	57	52	48	45
480	47	41	37	34
490	36	29	23	

Table 5. Average rupture stress values for ASTM steel A 335 Grades P11 and P12

Temperature °C	Values of average rupture stress (N/mm^2) for lifetime (h)			
	100 000	150 000	200 000	250 000
480	210	194	180	170
490	177	161	148	139
500	146	132	122	114
510	121	108	99	91
520	99	87	79	74
530	81	71	64	59
540	67	57	52	48
550	54	46	42	39
560	43	38	34	32
570	35	31	28	26
580				

Table 6. Average rupture stress values for ASTM steel A 335 Grades P22(A) and P22 (N + T)

Temperature °C	Values of average rupture stress (N/mm^2) for lifetime (h)			
	100 000	150 000	200 000	250 000
450	221	209	203	198
460	204	192	186	181
470	186	175	169	164
480	170	158	152	147
490	153	141	135	130
500	137	126	119	113
510	122	110	103	98
520	107	95	89	84
530	93	82	77	74
540	79	73	68	64
550	69	63	58	55
560	59	54	50	47
570	51	47	43	41
580	44	40	37	35

2. For steels complying with ASTM A 182 and ASTM A 312

Based on the editions current in 1984, steels complying with ASTM A 182 and ASTM A 312 Grades 304, 316, 321 and 347 are acceptable.

The design stress values given in table 7 of this Enquiry Case may be used without verification of $R_{e(T)}$ values for materials certified as complying with the ASTM A 182 and ASTM A 312.

There is no limitation on the design pressure for these steels. Temperature limits are those indicated by the design stress tabulated.

In connection with hydraulic pressure testing of pipework, the value R_e is given in table 7.

In connection with flexibility analysis the following values should be used.

(a) the expansion allowances given in table 4.10 of BS 806 : 1990;

(b) the moduli of elasticity given in table 4.11.1 of BS 806 : 1990;

(c) the 1 % proof stresses given in table 8 of this Enquiry Case.

(d) the average rupture stress values given in appendix E of BS 806 : 1990 as follows:

Grade	Table E.3(3)	Grade	Table E.1(3)
A 182-304 H	304 S51	A 312-304 H	3605-304 S51
A 182-316 H	316 S51	A 312-316 H	3605-316 S51, S52
A 182-321 H	321 S51-510	A 312-321 H	3605-321 S51, (1010)
A 182-347 H	347 S51	A 312-347 H	3605-347 S51

Table 7. Design stress value for forgings (ASTM A 182), and pipe (ASTM A 312)

Figures in parentheses refer to the notes following this table.

Grade	R_m		R_e (3)		Values of f (N/mm^2) for design temperatures (°C) not exceeding																								Design lifetime h	Notes
	p.s.i	N/mm^2	p.s.i	N/mm^2	50	100	150	200	250	300	350	400	450	500	520	540	550	560	580	590	600	620	640	650	660	680	700	720		
304 L	70 000	485	25 000	170	137	122	107	97	91	86	83	78	77																	
304	75 000	515	30 000	205	153	136	119	109	103	98	93	89	87																	
304 H (2)	75 000	515	30 000	205	153	136	119	109	103	98	93	89	87	85			83		82	81	76	65	55	50	45	38	33	28	100 000	1
																			82	78	72	61	51	46	42	36	31		150 000	
																			81	75	69	58	48	44	40	34	30		200 000	
																			81	72	66	55	46	42	38	33	29		250 000	
316 L	70 000	485	25 000	170	135	121	107	99	93	89	85	82	79																	
316	75 000	515	30 000	205	160	143	127	118	111	106	101	99	96																	
316 H (2)	75 000	515	30 000	205	160	143	127	118	111	106	101	99	96	93			90		89	88	88	74	58	53	46	35	28	23	100 000	1, 2
																				88	85	66	52	46	41	32	25	19	150 000	
																				88	79	62	48	43	38	29	22	18	200 000	
																				85	75	58	45	40	35	27	22	18	250 000	
321	75 000	515	30 000	205	157	145	133	127	121	117	113	110	107																	
321 H	75 000	515	30 000	205	157	145	133	127	121	117	113	110	107	104		102	102	101	86		71	57	42	36	31				100 000	1
																102	101	93	78		64	49	36	32	27				150 000	
																102	97	89	74		58	45	33	28	25				200 000	
																100	93	85	71		55	42	31	26	22				250 000	
347	75 000	515	30 000	205	160	151	142	135	127	123	120	118	116																	
347 H	75 000	515	30 000	205	160	151	142	135	127	123	120	118	116	115		113	113	113	99		82	66	53	47	41	31	23		100 000	1
																	113	112	93		75	61	48	42	37	28	22		150 000	
																	113	106	88		72	58	45	39	34	25	19		200 000	
																	112	102	85		68	55	42	37	32	24	19		250 000	

NOTE 1. The general notes to table 3.2 of BS 806 : 1990 apply.

NOTE 2. The time-dependent values are lower than those established by experience and established values up to 10 % higher may be permitted subject to continued fitness for service reviews being instituted at two-thirds of the design lifetime (see **2.8** of BS 806 : 1990) and by agreement between the purchaser and the manufacturer (see **1.4.2.2**(c) of BS 806 : 1990), providing the resulting value does not exceed the lowest time-independent stress value given.

NOTE 3. R_e values are reported on the basis of 0.2 % proof stress.

Table 8. 1% proof stress values

Grade	Values of 1% proof stress (N/mm^2) at temperatures (°C) not exceeding												
	50	100	150	200	250	300	350	400	450	500	550	600	650
304 L	205	161	144	132	123	117	111	106	104				
304	230	178	160	147	139	132	125	120	117				
304 H	230	178	160	147	139	132	125	120	117	115	112	109	104
316 L	205	159	145	134	125	120	114	111	107				
316	240	189	172	159	150	143	137	133	129				
316 H	240	189	172	159	150	143	137	133	129	125	121	119	116
321	235	192	180	172	164	158	152	148	144				
321 H	235	192	180	172	164	158	152	148	144	140	138	135	130
347	240	204	192	182	172	166	162	159	157				
347 H	240	204	192	182	172	166	162	159	157	155	153	151	

Enquiry Case 806/2

Occasional loads

Enquiry

BS 806 does not make any provision for occasional loads such as wind gusts, shock from safety valves, pressure and flow transients, and earthquake. In practice, analysis is carried out to show compliance with ANSI/ASME B31.1. Can rules be given to confirm this practice when employing any of the following materials:

BS 3602 : Part 1 : 500 Nb
BS 3604 : Part 1 : 620-440
BS 3604 : Part 1 : 622
BS 3604 : Part 1 : 660
BS 3604 : Part 1 : 762
API 5L grade B
ASTM A 106 grade B
ASTM A 335 grade P11
ASTM A 335 grade P12
ASTM A 335 grade P22

Reply

The committee recognizes successful practice based on permissible stress criteria and assessment of component stress differing from those in BS 806. In the absence of provision for occasional loads the following rules may be used.

1. Stress due to occasional loads

The effects of pressure, weight, other sustained loads and occasional loads including earthquake shall comply with the following.

$$\frac{pd^2}{4t\,(d+t)} + \frac{0.75FM_A}{Z} + \frac{0.75FM_B}{Z} \leqslant kf_h$$

where

- p is the design pressure (in N/mm^2);
- d is the mean inside diameter of the pipe (in mm);
- t is the mean thickness of the pipe (in mm);
- F is the stress intensification factor as determined in item 2 of this Enquiry Case. In no case shall the product $0.75F$ be less than 1.0;
- M_A is the resultant moment loading on the cross section due to weight and other sustained loads (in N·mm) (see item 3 of this Enquiry Case);
- M_B is the resultant moment loading on the cross section due to occasional loads, such as wind gusts, shock from safety valves, pressure and flow transients, and earthquake (in N·mm) (see item 3 of this Enquiry Case). If calculation of moments due to earthquake is required, only one half of the earthquake moment range shall be used. Effects of anchor displacement due to earthquake may be excluded from the above equation if they are included in the calculation of the thermal stress range (see **4.11.2**(a) of BS 806 : 1990);
- Z is the section modulus (in mm^3);
- f_h is the permissible stress (in N/mm^2) at the design temperature determined as the lowest of the following values:
  - (a) $R_m/4$;
  - (b) the average tensile strength at temperature/4;

(c) $R_{e(T)}/1.5$ for material with specified elevated temperature values; or
$R_{e(T)}/1.6$ for material without specified elevated temperature values;
(d) S_{Rt} at 100 000 hours/1.5;
(e) the 1 % creep stress at 100 000 hours.

where R_m, $R_{e(T)}$ and S_{Rt} are as defined in **B.2** of BS 806 : 1990

NOTE. Values applicable to the listed materials are obtained from table 1 of this Enquiry Case.

k is a coefficient having the value 1.15 for occasional loads arising from events of duration less than 10 % of any 24 h operating period and 1.2 for occasional loads arising from events of duration less than 1 % of any 24 h operating period. Earthquake need not be considered as acting concurrently with wind.

2. Stress intensification factor *F*

The following values shall be used.

(a) *Elbows and pipe bends:*

$$F = \frac{0.9}{\lambda^{2/3}}$$

where

$$\lambda = \frac{tR}{r^2}$$

t is the mean thickness of pipe (in mm);
R is the radius of the bend (in mm);
r is the mean radius of the pipe (in mm).

(b) *Mitre bends:*

$$F = \frac{0.9}{\lambda^{2/3}}$$

where
λ is as determined in figure 4.11.1(7) of BS 806 : 1990.

(c) *Branches:*

$$F = \frac{0.9}{\lambda^{2/3}}$$

where either

(i) $\lambda = \frac{t_1}{r_1}$ for tees in accordance with figure 4.11.1(6)(a) of BS 806 : 1990, or

(ii) λ is determined in accordance with figures 4.11.1(6)(b) or 4.11.1(6)(c) of BS 806 : 1990.

3. Moments and section moduli

(a) *Straight through pipe and components including curved pipe and elbow*

The resultant moment shall be calculated as follows:

$$M_A = \sqrt{(M_{xA}^2 + M_{yA}^2 + M_{zA}^2)} \quad \text{and}$$

$$M_B = \sqrt{(M_{xB}^2 + M_{yB}^2 + M_{zB}^2)}$$

where the additional subscripts are used to define the direction of the moment, i.e. x, y or z.

The section modulus shall be that of the piping.

(b) *Branches of equal bore to the main*

The resultant moment of each leg shall be calculated separately as described in item 3(a) of this Enquiry Case.

The section modulus shall be that of the branch or main pipe. Moments shall be taken at the junction point of the legs (see figure 1 of this Enquiry Case).

(c) *Branches of unequal bore to main*

The resultant moment of each leg shall be calculated separately as described in item 3(a) of this Enquiry Case.

Moments shall be taken at the junction point of the legs (see figure 1 of this Enquiry Case), unless the designer demonstrates the validity of a less conservative method.

The resultant moment for the reduced branch outlet shall be calculated as follows:

$$M_A, M_B = \sqrt{(M_{x3}^2 + M_{y3}^2 + M_{z3}^2)}$$

The section modulus Z of the reduced branch shall be

$$\pi r_2{}^2 t_e$$

where

r_2 is the mean radius of the branch (in mm);

t_e is the effective branch wall thickness (in mm), being the lesser of the main thickness t_1 or the branch thickness t_2 multiplied by the stress intensification factor F derived from item 2(c) of this Enquiry Case.

The resultant moments for the main outlets shall be calculated as follows:

$$M_A, M_B = \sqrt{(M_{x1}^2 + M_{y1}^2 + M_{z1}^2)}$$

$$M_A, M_B = \sqrt{(M_{x2}^2 + M_{y2}^2 + M_{z2}^2)}$$

The section modulus Z shall be that of the pipe.

4. Flexibility factor *K*

The following flexibility factor shall be used.

(a) *Elbow and pipe bends:*

$$K = \frac{1.65}{\lambda}$$

where

λ is determined from item 2 (a) of this Enquiry Case.

(b) *Mitre bends:*

K is determined from figure 4.11.1(7) of BS 806 : 1990.

Single mitres shall be treated as widely spaced mitres with

$$R = \frac{r\,(1 + \cot\alpha)}{2}$$

(c) *Branches:*

$K = 1$

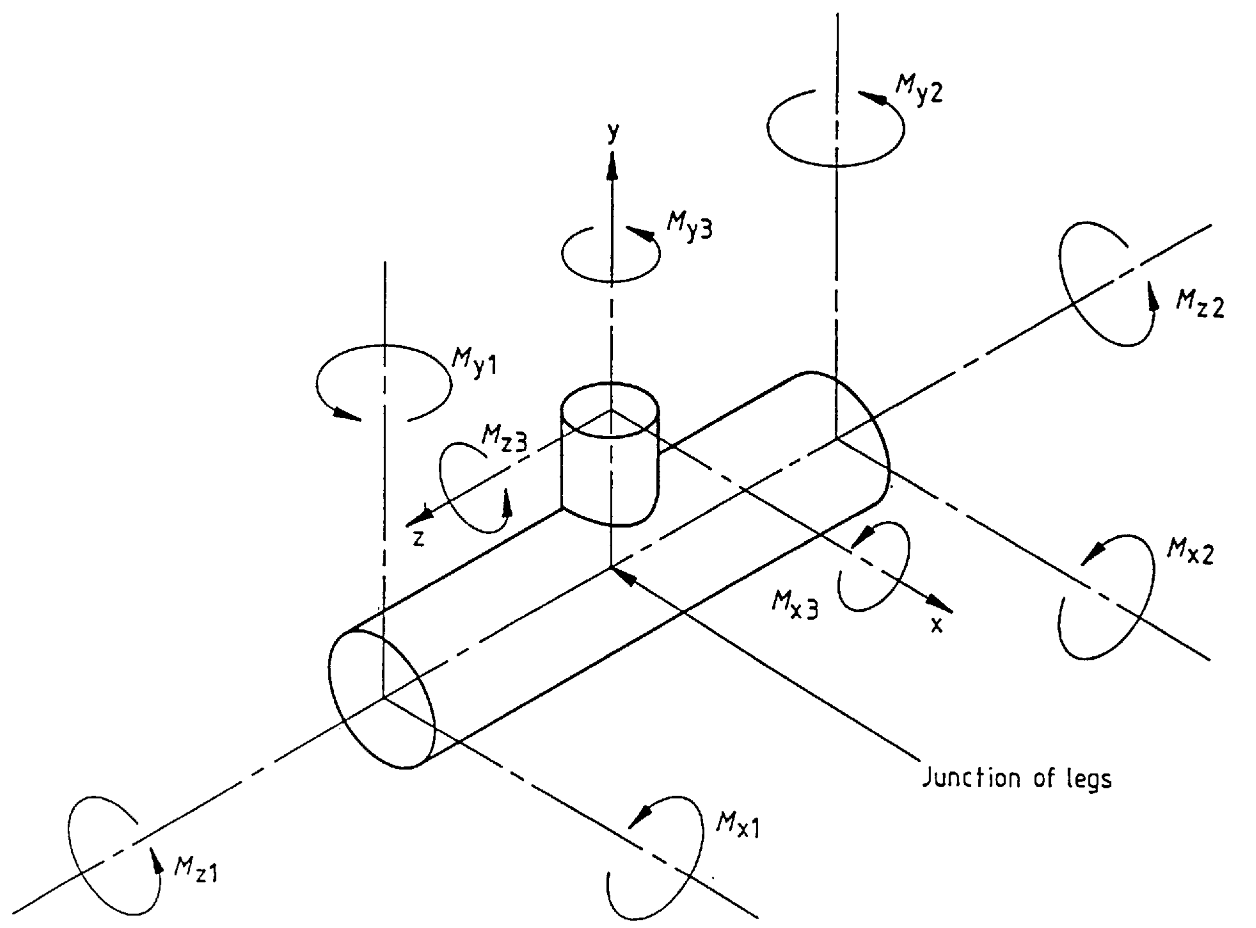


Figure 1. Moments: junction point of legs

Table 1. Maximum permissible stress for occasional loads

Standard	Steel grade	Values of f_h (N/mm^2) for design temperature (°C) not exceeding																
		20	100	150	200	250	300	350	390	400	410	420	430	440	450	460	470	480
BS 3602 : Pt 1	500 Nb	123	123	120	117	122	123	123	122	119	105	91	78	67	57	49	42	37
API 5L ASTM A 106	B B	103	103	103	103	103	103	102	93	89	84	78						

Standard	Steel grade	20	100	150	200	250	300	350	400	450	470	480	490	500	510	520	530	540	550	560	570	580	590
BS 3604	620-440	110	110	110	110	110	110	110	110	110	110	110	110	97	81	66	54	45	36	29	23		
BS 3604	622	123	123	123	119	119	120	120	120	115	113	112	102	91	81	71	62	53	46	39	34	29	
BS 3604	660	115	115	115	115	115	115	115	115	114	111	109	107	106	103	99	87	75	66	57	49		
ASTM A 335	P 11	103	103	103	103	103	103	103	103	102	95	91	86	81	76	64	53	43	37	31			
ASTM A 335	P 12	103	103	103	103	103	103	103	103	101	94	91	86	81	76	64	53	43	37	31			
ASTM A 335	P 22	103	103	103	103	103	103	103	103	100	94	91	86	81	76	68	62	52	48	43	39	35	30

Standard	Steel grade	20	100	150	200	250	300	350	400	450	480	490	500	510	520	530	540	550	560	570	580	590	600	610	620
BS 3604	762	173	173	173	169	164	160	155	150	140	134	132	130	126	122	119	106	93	81	69	59	50	42	35	29

Enquiry Case 806/3 : August 1987
to BS 806 : 1986
Issue 3, July 1991

Enquiry Case 806/3

Designing pipework in nuclear power stations to withstand safe shutdown earthquake (SSE)

Enquiry

BS 806 does not make any provision for designing pipework in nuclear power stations to withstand the safe shutdown earthquake (SSE) loading. Can rules be given to cater for this event when employing any of the following materials?

BS 3602 : Part 1 : 500 Nb
BS 3604 : Part 1 : 620-440
BS 3604 : Part 1 : 622
BS 3604 : Part 1 : 660
BS 3604 : Part 1 : 762

Reply

The committee recognizes the successful practice based on permissible stress criteria and assessment of component stresses differing from those in BS 806. In the absence of provision for SSE loading, the following rules may be used.

1. Stress due to SSE

The effects of pressure, weight, other sustained loads and SSE shall comply with the following.

$$\frac{pd^2}{4t(d+t)} + \frac{0.75FM_A}{Z} + \frac{0.75FM_B}{Z} \leqslant kf_j$$

where

- p is the design pressure (in N/mm^2);
- d is the mean inside diameter of the pipe (in mm);
- t is the mean thickness of the pipe (in mm);
- F is the stress intensification factor as determined in item 2 of this Enquiry Case. In no case shall the product $0.75F$ be less than 1.0;
- M_A is the resultant moment loading on the cross section due to weight and other sustained loads (in N·mm) (see item 3 of this Enquiry Case);
- M_B is the resultant moment loading on the cross section due to SSE (in N·mm) (see item 3 of this Enquiry Case). When calculating the moments due to SSE, only one half of the earthquake moment range shall be used. Effects of anchor displacement due to earthquake may be excluded from the above expression if they are included in the calculation of the thermal stress range (see **4.11.2**(a) of BS 806 : 1990);
- Z is the section modulus (in mm^3);
- f_j is the maximum permissible stress (in N/mm^2) at the design temperature determined as the lowest of the following values:
  - (a) $R_m/4$;
  - (b) the average tensile strength at temperature/4;
  - (c) $R_{e(T)}/1.5$ for material with specified elevated temperature values; or
    $R_{e(T)}/1.6$ for material without specified elevated temperature values.

  where R_m, $R_{e(T)}$ and S_{Rt} are as defined in **B.2** of BS 806 : 1990

  NOTE. Values applicable to the listed materials are obtained from table 1 of this Enquiry Case.
- k is a coefficient for SSE loading to be agreed between purchaser and manufacturer having a value of either:
  - 1.2 permitting the pipework or support to withstand the design loading without damage requiring repair; or
  - 2.4 permitting gross general deformations with some consequent loss of dimensional stability and damage requiring repair.

Enquiry Case 806/3 : August 1987
to BS 806 : 1986
Issue 2, July 1991

2. Stress intensification factor *F*

The following values shall be used.

(a) *Elbows and pipe bends:*

$$F = \frac{0.9}{\lambda^{2/3}}$$

where

$$\lambda = \frac{tR}{r^2}$$

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

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

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

(b) *Mitre bends:*

$$F = \frac{0.9}{\lambda^{2/3}}$$

where

λ is as determined in figure 4.11.1(7) of BS 806 : 1990.

(c) *Branches:*

$$F = \frac{0.9}{\lambda^{2/3}}$$

where either

(1) $\lambda = \frac{t_1}{r_1}$ for tees in accordance with figure 4.11.1(6)(a) of BS 806 : 1990; or

(2) λ is determined in accordance with figure 4.11.1(6)(b) or 4.11.1(6)(c) of BS 806 : 1990.

3. Moments and section moduli

(a) *Straight through pipe and components including curved pipe and elbow*

The resultant moment shall be calculated as follows:

$$M_A = \sqrt{(M_{xA}^2 + M_{yA}^2 + M_{zA}^2)} \quad \text{and}$$

$$M_B = \sqrt{(M_{xB}^2 + M_{yB}^2 + M_{zB}^2)}$$

where the additional subscripts are used to define the direction of the moment, i.e. x, y or z.

The section modulus shall be that of the piping.

(b) *Branches of equal bore to the main*

The resultant moment of each leg shall be calculated separately as described in item 3(a) of this Enquiry Case.

The section modulus shall be that of the branch or main pipe. Moments shall be taken at the junction point of the legs (see figure 1 of this Enquiry Case).

(c) *Branches of unequal bore to the main*

The resultant moment of each leg shall be calculated separately as in item 3(a) of this Enquiry Case.

Moments shall be taken at the junction point of the legs (see figure 1 of this Enquiry Case), unless the designer demonstrates the validity of a less conservative method.

The resultant moment for the reduced branch outlet shall be calculated as follows:

$$M_A, M_B = \sqrt{(M_{x3}^2 + M_{y3}^2 + M_{z3}^2)}$$

The section modulus Z of the reduced branch shall be

$$\pi {r_2}^2 t_e$$

where

r_2 is the mean radius of the branch (in mm);

t_e is the effective branch wall thickness (in mm), being the lesser of the main thickness t_1 or the branch thickness t_2 multiplied by the stress intensification factor F derived from item 2(c) of this Enquiry Case.

The resultant moments for the main outlets shall be calculated as follows:

$$M_A, M_B = \sqrt{(M_{x1}^2 + M_{y1}^2 + M_{z1}^2)}$$

$$M_A, M_B = \sqrt{(M_{x2}^2 + M_{y2}^2 + M_{z2}^2)}$$

The section modulus Z shall be that of the pipe.

4. Flexibility factor *K*

The following flexibility factor shall be used.

(a) *Elbow and pipe bends:*

$$K = \frac{1.65}{\lambda}$$

where

λ is determined from item 2(a) of this Enquiry Case.

(b) *Mitre bends:*

K is determined from figure 4.11.1(7) of BS 806 : 1990.

Single mitres shall be treated as widely spaced mitres with

$$R_f = \frac{r\,(1 + \cot\alpha)}{2}$$

(c) *Branches:*

$K = 1$

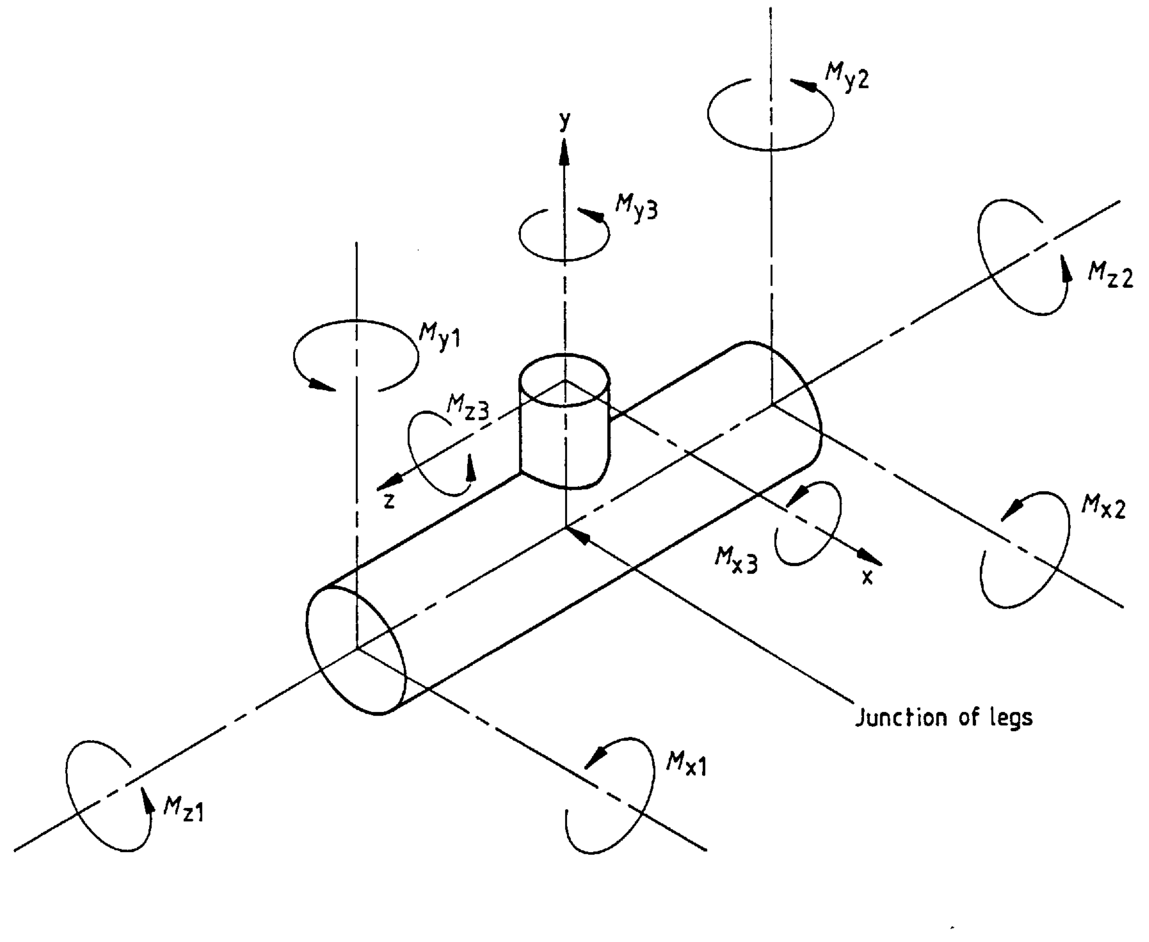


Figure 1. Moments: junction point of legs

Enquiry Case 806/3 : August 1987
to BS 806 : 1986
Issue 3, July 1991

Table 1. Maximum permissible stress for SSE conditions

Standard	Steel grade	Values of f_j (N/mm^2) for design temperature (°C) not exceeding																							
		20	100	150	200	250	300	350	390	400	410	420	430	440	450	460	470	480	490						
BS 3602 : Pt 1	500 Nb	123	123	120	117	122	123	123	–	121	118	116	113	110	107	105	102	99	96						
		20	100	150	200	250	300	350	400	450	470	480	490	500	510	520	530	540	550	560	570	580			
BS 3604	620-440	110	110	110	110	110	110	110	110	110	110	110	110	110	110	110	107	105	102	100	97	94			
BS 3604	622	123	123	123	119	119	120	120	120	115	113	112	111	110	108	106	104	102	100	98	96	95			
BS 3604	660	115	115	115	115	115	115	115	115	114	111	109	107	106	103	101	98	96	93	91	88	86			
		20	100	150	200	250	300	350	400	450	480	490	500	510	520	530	540	550	560	570	580	590	600	610	620
BS 3604	762	173	173	173	169	164	160	155	150	140	134	132	130	126	122	119	115	111	107	104	100	96	93	89	85

Enquiry Case 806/4

EFW Alloy pipe for wet steam applications

Enquiry

The cold reheat and bled steam pipework associated with wet steam turbine generators transports large quantities of medium temperature, low pressure, high wetness steam. To combat the corrosion-erosion phenomena pertinent to the conditions in the above systems, a pipe material containing 2 ¼ Cr 1Mo is required. BS 3604-622 seamless tube is not available with the required large bore sizes and thin wall sections. It is requested that an appropriate tube is recommended.

Reply

It is considered appropriate that where the design stress is time independent and where large diameter tubes with a thin wall section are required, it is acceptable to manufacture the tubes from steel plate or sheet longitudinally welded continuously across the abutting edges by an automatic submerged arc welding process using at least one pass on the inside and at least one pass on the outside of the tube.

Steel complying with grade 622/515A of BS 1501 : Part 2 is acceptable, provided that the sulphur content is limited to 0.015 %.

Prior to forming, the plate should be ultrasonically examined to grade L4 of BS 5996.

On completion of the tube fabrication, each axial seam weld should be stress relieved at a temperature as stipulated in table 6 of BS 2633 : 1987.

100 % non-destructive inspection of the weld of each stress relieved tube should be carried out in accordance with table 1 of this Enquiry Case.

The design stresses are given in table 2 of this Enquiry Case.

In connection with the hydraulic testing of pipework, the value of R_e, the specified minimum yield stress, should be taken as 310 N/mm^2.

In connection with the flexibility analysis, the following values should be used:

(a) the expansion allowances given for low alloy steels in table 4.10 of BS 806 : 1986;

(b) the moduli of elasticity given in table 4.11.1 of BS 806 : 1986;

(c) the 0.2 % proof stress given in table 3 of this Enquiry Case.

Pipe bends may be made by one of the following processes: hot forming; by welding together halves pressed from plate; or by mitring pieces of pipe. All bends should comply with section four of BS 806 : 1986. Mitre bends should be made only by cutting the faces of adjacent segments at the same angle α which should not exceed 11.25 °.

The angle α is as shown in figure 4.4.2.2 of BS 806 : 1986.

Enquiry Case 806/4 : October 1989
to BS 806 : 1986

Table 1. Weld inspection

Weld type	Inspection	Technique	Acceptance Standard
Longitudinal seam welds	100 % Radiography	BS 2600 : Part 1	Appendix B of BS 3602 : Part 2 : 1978
	100 % M.P.I.	BS 6072	BS 2633
Circumferential seam welds	100 % Radiography	BS 2910	BS 2633
	100 % M.P.I.	BS 6072	BS 2633

Table 2. Design stress values

Steel grade	Value of f (N/mm^2) for design temperatures (°C) not exceeding							
	50	100	150	200	250	300	350	400
622/515A of BS 1501 : Part 2	207	192	177	172	166	163	158	153

Table 3. 0.2 % Proof stress values

Steel grade	Value of 0.2 % proof stress (N/mm^2) at temperatures (°C) not exceeding							
	20	100	150	200	250	300	350	400
622/515A of BS 1501 : Part 2	303	292	283	275	266	260	252	245

Enquiry Case 806/5 : March 1990
to BS 806 : 1990
Issue 2, January 1991

Enquiry Case 806/5

Single non-repeated anchor/restraint movements

Enquiry

BS 806 does not make any provision for stresses developed by single non-repeated anchor/restraint movements which are typified by building settlement. Can guidance be given to cater for this event?

Reply

In the absence of provision for single non-repeated anchor/restraint movements, the committee considers that the effects of any such movements should comply with the following.

(a) The stress should be calculated in accordance with **4.11** of BS 806 : 1990 taking the single non-repeated anchor/restraint movement as the sole applied load. The cold condition elastic modulus should be used in the calculation.

(b) Where the design stress as given in table 3.2 of BS 806 : 1990 is time independent, the calculated stress should not exceed $0.75 R_m$, where R_m is the minimum tensile strength (in N/mm^2) specified, for the grade of steel concerned, at room temperature (tested in accordance with BS EN 10 002).

(c) Where the design stress, as given in table 3.2 of BS 806 : 1990, is time dependent, the calculated stress should not exceed the following values.

(1) For ferritic steels, 0.3 × 0.2 % proof stress (in N/mm^2) at the design temperature as listed in table E.1(1) of BS 806 : 1990.

(2) For austenitic steels, 0.3 × 1 % proof stress (in N/mm^2) at the design temperature as listed in table E.1(2) of BS 806 : 1990.

Caution

Local overstrain

It is possible that a small part of a pipe system will undergo considerable inelastic strain when the rest of the system is almost entirely elastic. This happens when the part concerned is appreciably weaker than the rest, either due to reduced section size, weaker material or higher temperature. Conditions likely to cause significant inelastic strain should preferably be avoided. If this is not possible, a more complete inelastic analysis should be undertaken.

STANDARDS

Enquiry Case 806/6 : January 1991
to BS 806 : 1990

Enquiry Case 806/6

Use of buttwelding pipe fittings

Enquiry

Under what conditions may buttwelding fittings to BS 1640 and BS 1965 : Part 1 be used in BS 806 pipework systems?

Reply

For buttwelding fittings complying with BS 1640 or BS 1965 : Part 1, the following should be observed.

Permissible Stress Level

Design 'stress values' should be taken from table 3.2 of BS 806 : 1990 when the material from which the fittings are formed is listed.

When the material from which the fittings are formed is not listed in table 3.2 then stress levels may be taken from Enquiry Case 806/1 or deduced from appendix B of BS 806 : 1990.

Design

The requirements of section 4 of BS 806 : 1990 should be satisfied.

In the case of 'T' pieces designed in accordance with 4.8 of BS 806 : 1990, the minimum thicknesses of the 'T' pieces are defined as the lowest thicknesses applicable to the 'T' piece or the connecting pipes for the main and the branch. The buttweld and the connecting pipes may be regarded as forming part of the reinforcement.

STANDARDS

Enquiry Case 806/7

Testing of pipe bends

Enquiry

Clause **6.1.1** of BS 806 : 1990 specifies that completed wrought steel pipes and fittings shall be hydraulic pressure tested. This pressure test may be waived under the circumstances which apply in **6.1.3** of BS 806 : 1990. Specifically this waiver may be applied to pipes that have been examined in accordance with **6.1.3**(a) and have been subjected to only limited manipulation and fabrication work as defined in **6.1.3**(b). Would it be admissible to add bending to the operations listed in **6.1.3**(b) for pipes that have been ultrasonically tested in accordance with **6.1.3**(a)(1)?

Reply

The committee considers that for pipe bends that have been formed from pipe ultrasonically examined in accordance with **6.1.3**(a)(1), the requirement for hydraulic testing may be waived provided that ultrasonic examination is carried out after bending, in accordance with the following.

(a) The ultrasonic examination should extend over the full extent of the pipe bend and should cover a minimum of the extrados to the neutral axis.

(b) Examination should be carried out by an ultrasonic shear wave method, using equipment with the same ultrasonic parameters and calibrated to the same sensitivity as used in the ultrasonic examination of the original straight pipe. Any bend producing a signal lower than the test sensitivity should be deemed to have passed this test. Where a signal equal to, or greater than, the test sensitivity is obtained, the bend should be designated suspect.

(c) For suspect bends, the following action may be taken.

(1) If it can be proved that the signal arises from a combination of minor imperfections, not in themselves deep enough to cause rejection, the bend should be deemed acceptable.

(2) The suspect area may be explored by grinding, or dressing by an acceptable method and, after checking that the remaining thickness is within thickness tolerance, the bend should be re-examined ultrasonically in accordance with this procedure and if all signals are then lower than the test sensitivity, the bend should be deemed acceptable.

(3) Suspect bends not meeting the requirements of (1) or (2) should be rejected.

Publications referred to

BS 10 Specification for flanges and bolting for pipes, valves and fittings (obsolescent)

BS 21 Specification for pipe threads for tubes and fittings where pressure-tight joints are made on the threads (metric dimensions)

BS 143 & 1256 Specification for malleable cast iron and cast copper alloy threaded pipe fittings

BS 759 Valves, gauges and other safety fittings for application to boilers and to piping installations for and in connection with boilers
Part 1 Specification for valves, mountings and fittings

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

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 1452 Specification for flake graphite cast iron

BS 1503 Specification for steel forgings for pressure purposes

BS 1504 Specification for steel castings for pressure purposes

BS 1560 Circular flanges for pipes, valves and fittings (Class designated)
Section 3.1 Specification for steel flanges

BS 1640 Specification for steel butt-welding pipe fittings for the petroleum industry

BS 1740 Specification for wrought steel pipe fittings (screwed BS 21 R-series thread)

BS 1821 Specification for class 1 oxy-acetylene welding of ferritic steel pipework for carrying fluids

BS 1965 Specification for butt-welding pipe fittings for pressure purposes
Part 1 Carbon steel

BS 2633 Specification for Class I arc welding of ferritic steel pipework for carrying fluids

BS 2640 Specification for Class II oxy-acetylene welding of carbon steel pipework for carrying fluids

BS 2789 Specification for spheroidal graphite or nodular graphite cast iron

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

BS 2910 Methods for radiographic examination of fusion welded circumferential butt joints in steel pipes

BS 2971 Specification for class II arc class welding of carbon steel pipework for carrying fluids

BS 3100 Specification for steel castings for general engineering purposes

BS 3500 Methods for creep and rupture testing of metals

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 weld 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 welde tubes

BS 3605 Austenitic stainless steel pipes and tubes for pressure purposes
Part 1 Specification for seamless tubes

BS 3799 Specification for steel pipe fittings, screwed an socket-welding for the petroleum industry

BS 3920 Derivation and verification of elevated temperature properties for steel products for pressure purposes
Part 1 Method of deriving the minimum elevated temperature yield or proof stress properties when data on a minimum of 50 casts are available
Part 2 Method for deriving the elevated temperature yield or proof stress properties when data are limited

BS 3923 Methods for ultrasonic examination of welds
Part 1 Methods for manual examination of fusio welds in ferritic steels

BS 3974 Specification for pipe supports

BS 4204 Specification for flash welding of steel tubes for pressure applications

BS 4504 Circular flanges for pipes, valves and fittings (PN designated)
Section 3.1 Specification for steel flanges

BS 4622 Specification for grey iron pipes and fittings

BS 4677 Specification for arc welding of austenitic stainless steel pipework for carrying fluids

BS 4772 Specification for ductile iron pipes and fittings

BS 4882 Specificaiton for bolting for flanges and pressure containing purposes

BS 5046 Method for the estimation of equivalent diameters in the heat treatment of steel

BS 5500 Specification for unfired fusion welded pressure vessels

BS 5750 * Quality systems

BS 6072 Method for magnetic particle flaw detection

BS 6129 Code of practice for the selection and application of bellows expansion joints for use in pressure systems
Part 1 Metallic bellows expansion joints

BS 6208 Method for ultrasonic testing of ferritic steel castings including quality levels

BS 6443 Method for penetrant flaw detection

BS 6759 Safety valves
Part 1 Specification for safety valves for steam and hot water

* Referred to in the foreword only.

BS 7079	Preparation of steel substrates before application of paints and related products Part A1 Specification for rust grades and preparation grades of uncoated steel substrates and of steel substrates after overall removal of previous coatings
BS 7339	Code of practice for supplementary checking of metallic materials of construction in pressurized systems
BS EN 10002	Tensile testing of metallic materials Part 1 Method of test at ambient temperature Part 5 Method of test at elevated temperatures
PD 6510	A review of the present state of the art of assessing remnant life of pressure vessels and pressurized systems designed for high temperature service

Standards significant to Health and Safety at Work*†

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
PM 60†	Steam boiler blow down systems

*Referred to in the foreword only.

† Published by the Health and Safety Executive.

‡ Published by the American Society for Testing and Materials.

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