

OBSOLESCE
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Specification for

Carbon and low alloy steel containment structures for stationary nuclear power reactors

Co-operating organizations

The Nuclear Energy Industry Standards Committee, under whose supervision this British Standard was prepared, consists of representatives from the following Government departments and scientific and industrial organizations:

Association of Consulting Engineers*
 British Electrical & Allied Manufacturers Association*
 British Insurance (Atomic Energy) Committee*
 British Mechanical Engineering Federation*
 Electricity Council, the Generating Board and the Area Boards in England and Wales*
 Institution of Chemical Engineers
 Institution of Electrical Engineers
 Institution of Mechanical Engineers
 Lloyd's Register of Shipping*
 Ministry of Labour (H.M. Factory Inspectorate)*
 Ministry of Power*
 Scientific Instrument Manufacturers' Association of Great Britain
 United Kingdom Atomic Energy Authority*

The Government departments and scientific and industrial organizations marked with an asterisk in the above list, together with the following, were directly represented on the committee entrusted with the preparation of this British Standard:

Associated Engineering Insurers (British Electricity) Management Committee
 Associated Offices Technical Committee
 Board of Trade (Marine Division)
 British Iron & Steel Federation
 Ministry of Defence (Navy Department)
 Ministry of Technology (National Engineering Laboratory)
 Tank & Industrial Plant Association
 Water Tube Boilermakers Association

This British Standard, having been approved by the Nuclear Energy Industry Standards Committee and endorsed by the Chairman of the Engineering Divisional Council, was published under the authority of the General Council on 30 September 1967

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Foreword

This standard makes reference to the following British Standards:

BS 131, *Methods for notched bar tests. Part 2: The Charpy V-notch impact test.*

BS 427, *Method for Vickers hardness test. Part 1: Testing of metals.*

BS 499, *Welding terms and symbols. Part 1: Welding, brazing and thermal cutting glossary.*

BS 903, *Methods of testing vulcanized rubber. Part A7: Determination of hardness.*

BS 1500, *Fusion welded pressure vessels for use in the chemical, petroleum and allied industries. Part 1: Carbon and low alloy steels.*

BS 1501, *Steels for fired and unfired pressure vessels. Plates.*

BS 1501-6, *Steels for use in the chemical, petroleum and allied industries.*

BS 1510, *Steels for use in the chemical, petroleum and allied industries (Low temperature supplementary requirements to BS 1501-1506).*

BS 1560, *Steel pipe flanges and flanged fittings (nominal sizes $\frac{1}{2}$ in to 24 in) for the petroleum industry.*

BS 1780, *Bourdon tube pressure and vacuum gauges.*

BS 1806, *Dimensions of toroidal sealing rings ("O" seals and their housings).*

BS 1966, *Domed ends for tanks and pressure vessels.*

BS 2094, *Glossary of terms relating to iron and steel.*

BS 2600, *General recommendations for the radiographic examination of fusion welded butt joints in steel.*

BS 2633, *Class I arc welding of ferritic steel pipework for carrying fluids.*

BS 2910, *General recommendations for the radiographic examination of fusion welded circumferential butt joints in steel pipes.*

BS 3059, *Steel boiler and superheater tubes.*

BS 3455, *Glossary of terms used in nuclear science.*

BS 3601, *Steel pipes and tubes for pressure purposes. Carbon steel: ordinary duties.*

BS 3602, *Steel pipes and tubes for pressure purposes. Carbon steel: high duties.*

BS 3603, *Steel pipes and tubes for pressure purposes. Carbon and alloy steel: low temperature duties.*

BS 3604, *Steel pipes and tubes for pressure purposes. Low and medium alloy steel.*

BS 3971, *Image quality indicators for radiography and recommendations for their use.*

CP 3:Chapter V, *Loading.*

At its meeting at Harrogate in June 1958, Sub-committee 3, Reactor Safety, of Technical Committee 85, Nuclear Energy, of the International Organization for Standardization, decided to study aspects of reactor containment. In preparing this British Standard, therefore, the BSI Committee has given careful consideration to documents placed before the ISO Sub-committee, and in particular to the Proposed Safety Code for Design, Fabrication and Maintenance of Containment Structures for Stationary Atomic Power Reactors submitted by the U.S.A., and assistance received from this source is hereby acknowledged. In preparing this standard such additional requirements have been taken into consideration, together with any information available to the ISO committee. Account has also been taken of the higher design stresses recently accepted by the ISO Boiler committee. It is intended that this standard shall be frequently reviewed in the light of further ISO discussions.

Attention is drawn to the fact that this standard is concerned with design, construction, inspection and testing aspects of the containment structure, but does not discuss the circumstances in which, or the extent to which, containment shall be provided: this will be specified by the purchaser. Other British Standards are in course of preparation which will give guidance in this connection.

It was desired to rationalize the approach to design and to this end Section 3.3 has been introduced which requires detailed design appraisal in the light of the modes of failure relevant to the particular structure. It is appreciated that this section at present is not as detailed as might be considered desirable in order to achieve uniformity. However, the committee were of the opinion that the introduction of these principles in their present form served a useful purpose and, therefore, should not be delayed pending more detailed information becoming available.

Where sections of this standard have been taken from other British Standards they have been repeated in full to avoid possible confusion. Some assistance has been obtained from consideration of other standards, notably ASME, and in particular the section of this standard dealing with flange design has largely been based on the relevant sections of ASME Section VIII. This was done because it was apparent that this method is almost universally used by designers in this particular field.

Unless otherwise defined in this standard, the terms used are consistent with those used in other British Standards or standard dictionaries and BS 2094¹⁾, BS 499, Part 1²⁾ and BS 3455³⁾ should be consulted for definitions not given.

NOTE 1 Where metric equivalents are stated in parentheses the figures in British units are to be regarded as the standard. The metric equivalents are approximate. More accurate conversions should be based on the tables in BS 350, "Conversion factors and tables". Attention is also drawn to BS 2856, "Precise conversion of inch and metric sizes on engineering drawings".

NOTE 2 With the exception of 3.2.3 and 3.2.8 the equations in Section 3 are valid for any coherent system of units.

Obsolescent (by Amendment No. 1)

The need for the continuance of this British Standard has been reviewed and it has been decided that it should be regarded as obsolescent. The standard will be withdrawn in due course.

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

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

Summary of pages

This document comprises a front cover, an inside front cover, pages i to vi, pages 1 to 97 and a back cover.

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

¹⁾ BS 2094, "Glossary of terms relating to iron and steel".

²⁾ BS 499, "Welding terms and symbols", Part 1, "Welding, brazing and thermal cutting glossary".

³⁾ BS 3455, "Glossary of terms used in nuclear science".

Section 1. General

1.1 Scope

This British Standard covers the design, construction, inspection and testing of steel reactor containment structures made of carbon and low alloy steel for temperatures not exceeding 300 °C. Such structures are not in contact with the reactor coolant during normal operation. Pressure-relieved structures are not excluded, provided they are of a form that contains the fission products or ensures their safe disposal. Attachments such as airlocks or piping that is or may become directly connected between the interior of the containment structure and a closure, and may therefore contain radioactive material released during accidents, is considered part of the containment structure.

Where the words “purchaser” and “manufacturer” occur in the text they shall be taken to include representatives of the purchaser or manufacturer.

1.2 Definitions

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

containment structure

a sealed structure or building, including its integral supports, enclosing a nuclear reactor and some or all of the ancillary circuits containing radioactive materials during operation. This is designed to prevent, or to limit to a permissible amount, the escape of radioactive substances in the event of a reactor accident

ligament efficiency

the ratio of an arbitrary strength of a ligament to the strength of the unpierced plate, expressed as a decimal

nominal design stress

the stress value to be selected in accordance with 2.3 for use in the formulae in 3.2, Basic design

specified accident design conditions

the combinations of conditions, specified by the purchaser, for which the structure is to be designed

normal working pressure

the maximum pressure that will occur in the relevant part of the structure during normal operation

normal design pressure

a value or values specified by the purchaser (see 3.1.1) used in all calculation to determine the minimum thickness of the various components of the structure. The design pressure shall not be less than the normal working pressure

accident design pressure (internal or external)

a value or values specified by the purchaser (see 3.1.1) used in all calculations to determine the minimum thickness of the various component parts of the structure

normal design temperature

the maximum estimated temperature which will occur in the relevant part of the structure during normal operation

minimum design temperature

the minimum temperature specified by the purchaser for which the relevant part of the structure is to be designed

accident design temperature

the maximum estimated temperature which will occur in the relevant part of the structure under the specified accident design conditions

NOTE Design condition
Design pressure
Design temperature } Whenever these terms are used in this standard they shall be taken to refer to the values appropriate to the normal design condition or the accident design condition, whichever governs.

1.3 Information to be supplied by the purchaser and manufacturer

In addition to information to be supplied in accordance with the detailed requirements of this standard:

- a) The purchaser shall specify to the manufacturer at the time of the enquiry:
 - i) The name of the inspecting authority representing the purchaser.
 - ii) Any requirements in excess of the minimum requirements of this standard.
 - iii) Any statutory or other regulations with which the vessel is required to comply.
- b) The manufacturer shall supply to the purchaser and/or the inspecting authority sufficiently detailed drawings to enable the compliance of the structure to this standard to be established.

1.4 Agreed specification

A document shall be compiled by the manufacturer, covering all the material specifications for the materials of construction of the structure and the acceptance values for all the mechanical tests required by this standard, as agreed between him and the purchaser.

1.5 Interpretation

If any ambiguity be found or doubt arise as to the meaning or effect of any part of this standard or as to whether anything ought to be done or omitted to be done in order that this standard should be complied with in full, the question shall be referred to the Nuclear Reactor Safety Technical Committee of the British Standards Institution whose interpretation of the requirements of this standard upon the matter at issue shall be given free of charge and shall be final and conclusive. Parties adopting this standard for the purposes of any contract shall be deemed to adopt this provision unless by their contract they either expressly exclude it or else import an arbitration provision in terms extending to the interpretation of this standard. But this provision is limited to questions of interpretation and does not confer on the Committee any power or jurisdiction to adjudicate upon the contractual rights or duties of any person under a contract except so far as they may necessarily be affected by the interpretation arrived at by the Committee.

Findings or rulings of the Committee upon matters of interpretation may be incorporated as “addenda” to the standard and if so incorporated shall be treated as amendments thereto.

Section 2. Materials and nominal design stresses

2.1 General

This section covers the selection of materials and nominal design stresses except where otherwise stated.

2.2 Selection of materials

2.2.1 The selection of the materials of construction for pressure containing parts and their integral attachments shall take into account the suitability of the material with regard to fabrication and all the modes of failure relevant to the conditions of operation of the structure covered by the design. The contractor shall justify his choice of materials to meet the requirements to the satisfaction of the purchaser.

2.2.2 All the materials used in the manufacture of pressure parts of structures constructed to this standard shall be in accordance with the appropriate material specifications listed in Table 1 except as otherwise permitted in this Section. In addition, the requirements of BS 1510⁴⁾ and BS 3603⁵⁾ may apply so that, in the final condition of the part in the structure, the material can be expected to be in a notch ductile condition at the minimum design temperature; the criterion of notch ductility shall be as agreed between the manufacturer and the purchaser.

The materials used in welding shall satisfy the requirements of 4.2 of this standard. Attention is drawn to the fact that the long term properties of weld metal may differ from those of the parent metal and this shall be taken into account where relevant.

Carbon and low alloy steel castings may be used for pressure parts subject to agreement between the purchaser and the manufacturer.

2.2.3 Other carbon and low alloy steels of specified chemical composition may be used for pressure parts of structures by express agreement between the manufacturer and the purchaser provided that:

- 1) All the relevant mechanical properties of the materials are available from a representative number of production casts.

These shall cover the same properties as those covered in the material specifications listed in Table 1. Information shall also be available to enable the nominal design stresses to be calculated in accordance with the requirements of 2.3 for the relevant design temperatures.

- 2) The nominal design stresses for the material are derived in accordance with the requirements of 2.3.

2.2.4 The materials of construction of non-pressure parts integrally welded to pressure containing parts, shall be so chosen as not to impair the integrity of the pressure part.

2.2.5 The materials of construction of components other than pressure containing parts or welded attachments thereto, but which are intended by design to contribute to the integrity of the structure, shall conform to an approved specification.

2.2.6 Corrosion resistant linings shall not be included in the computations for the required wall thickness, except in the case of clad steels as may be agreed between the manufacturer and the purchaser.

2.3 Nominal design stresses

2.3.1 Nominal design conditions

a) *General.* The following criteria have been used to obtain the nominal design stresses for materials given in Table 1 and shall be used to calculate the corresponding values for materials not covered by these tables but otherwise meeting the requirements of 2.2.3.

i) *Components*

$$\left. \begin{aligned} \text{Nominal design stress} &= \frac{R_{20}}{2.7} \\ \text{or} &= \frac{E_t}{1.5} \end{aligned} \right\} \begin{array}{l} \text{whichever is} \\ \text{lower} \end{array}$$

where R_{20} = minimum value of ultimate tensile strength specified for the material at room temperature.

E_t = minimum value of yield point (0.2 per cent proof stress) at normal design temperature or the nearest higher temperature for which it can be determined.

ii) *Bolting materials.* The following criteria shall be used to obtain the nominal design stress for bolting materials meeting the requirements of this section.

$$\left. \begin{aligned} \text{Nominal design stress} &= \frac{E_{20}}{5} \\ \text{or} &= \frac{E_t}{3} \end{aligned} \right\} \begin{array}{l} \text{whichever is} \\ \text{lower} \end{array}$$

⁴⁾ BS 1510, "Steels for use in the chemical, petroleum and allied industries: low temperature supplementary requirements to BS 1501-BS 1506".

⁵⁾ BS 3603, "Steel pipes and tubes for pressure purposes, carbon and low alloy steel — low temperature duties".

where E_t is as given above and E_{20} is the specified minimum yield strength at room temperature.

Credit may be taken for the enhancement of properties resulting from heat treatment provided that it can be shown by the manufacturer that such heat treatment remains effective under the design conditions of the bolting.

2.3.2 Accident design conditions

a) *General*. The following criteria shall be used to obtain the nominal design stress values for materials given in Table 1 or meeting the requirements of **2.2.3**:

i) *Components*

$$\left. \begin{aligned} \text{Nominal design stress} &= \frac{1.1R_{20}}{2.7} \\ \text{or} &= \frac{1.1E_t}{1.5} \end{aligned} \right\} \begin{array}{l} \text{whichever} \\ \text{is lower} \end{array}$$

where R_{20} is as defined above

and E_t = minimum value of yield point (0.2 per cent proof stress) for the material at the temperature appropriate to the accident design conditions or the nearest higher temperature for which it can be determined.

Attention is drawn to the need to determine the most severe combination of pressure, temperature and other loadings which may occur following an accident.

ii) *Bolting materials*. The nominal design stress values for bolting shall be the same as those permitted by **2.3.1 a) ii)** above, except that E_t shall be as defined in **2.3.2 a) i)**.

2.3.3 Modulus of elasticity. Table 2 gives values for the materials listed in Table 1. The values have been established from a large number of experiments and are suitable for design purposes.

Table 1A — Permissible materials (see 2.2.2)

Form	Material	Specification
Plate	Carbon steel (semi-killed) Carbon steel (silicon-killed) Carbon manganese steel (semi-killed) Carbon manganese steel (semi-killed, niobium treated) Carbon manganese steel (silicon-killed) Carbon manganese steel (silicon-killed, aluminium treated) $\frac{1}{2}$ per cent chromium $\frac{1}{2}$ per cent molybdenum steel $\frac{3}{4}$ per cent chromium $\frac{1}{2}$ per cent molybdenum steel	BS 1501-151 ^a BS 1501-161 ^a BS 1501-211 ^a BS 1501-213 ^a BS 1501-221 ^a BS 1501-224 ^a BS 1501-620A ^b BS 1501-620B ^b
Bars and Sections		In course of preparation
Forgings	Carbon steel (silicon-killed) Carbon manganese steel 1 per cent chromium $\frac{1}{2}$ per cent molybdenum steel	BS 1503-161 ^b BS 1503-221 ^b BS 1503-620 ^b
Pipes and Tubes	Carbon steel: ordinary duties: hot finished cold drawn elec. resist, welded Carbon steel: high duties: hot finished cold drawn elec. resist, welded Carbon steel: low temperature duties: hot finished cold drawn Low and medium alloy steel: 1 per cent chromium $\frac{1}{2}$ per cent molybdenum steel: hot finished cold drawn $1\frac{1}{4}$ per cent chromium $\frac{1}{2}$ per cent molybdenum steel: hot finished cold drawn $\frac{1}{2}$ per cent chromium $\frac{1}{2}$ per cent molybdenum $\frac{1}{4}$ per cent vanadium steel: hot finished cold drawn	BS 3601-HFS ^c BS 3601-CDS ^c BS 3601-ERW ^c BS 3602-HFS ^d BS 3602-CDS ^d BS 3602-ERW ^d BS 3603-HFS ^e BS 3603-CDS ^e BS 3604-HF620 ^f BS 3604-CD620 ^f BS 3604-HF621 ^f BS 3604-CD621 ^f BS 3604-HF660 ^f BS 3604-CD660 ^f
Tubes		BS 3059 ^g

^a BS 1501, "Steels for fired and unfired pressure vessels. Plates".^b BS 1501-6, "Steels for use in the chemical, petroleum and allied industries".^c BS 3601, "Steel pipes and tubes for pressure purposes. Carbon steel: ordinary duties".^d BS 3602, "Steel pipes and tubes for pressure purposes. Carbon steel: high duties".^e BS 3603, "Steel pipes and tubes for pressure purposes. Carbon and low alloy steel: low temperature duties".^f BS 3604, "Steel pipes and tubes for pressure purposes. Low and medium alloy steel".^g BS 3059, "Steel boiler and superheater tubes".

Table 1B — Nominal design stresses for plates

BS ref.	Nominal tensile design stress (lbf/in ² × 10 ³) at temperature °C					Notes	BS ref.	Nominal tensile design stress (lbf/in ² × 10 ³) at temperature °C					Notes
	100°	150°	200°	250°	300°			100°	150°	200°	250°	300°	
BS 1501 ^a 151-Gr 23A 26A f8A	13.74 15.54 16.71	13.74 15.54 16.71	13.74 15.54 16.71	13.74 15.54 16.71	12.37 13.96 15.05		BS 1501 ^a 213-Gr 28A 30A 32A	16.71 17.94 19.12	16.71 17.94 19.12	16.71 17.94 19.12	16.71 17.94 19.12	15.05 16.10 17.15	
BS 1501 ^a 151-Gr 23B 26B 28B	16.72 18.99 20.45	16.28 18.36 19.85	15.53 17.62 18.96	14.19 16.14 17.33	12.40 14.05 15.09	Up to and including 1 1/4 in thick.	BS 1501 ^a 213-Gr 28B 30B 32B	23.25 24.90 26.55	23.25 24.90 26.55	23.25 24.90 26.55	21.38 22.85 24.35	18.66 20.00 21.20	Up to and including 2 1/2 in thick. For over 2 1/2 in thick see material specification.
BS 1501 ^a 151-Gr 23B 26B 28B	15.84 17.92 19.25	15.23 17.17 18.51	14.64 16.58 17.77	13.75 15.53 16.73	12.40 14.05 15.09	Over 1 1/4 in, up to and including 2 1/2 in thick.	BS 1501 ^a 221-Gr 26A 28A 30A 32A	15.54 16.71 17.94 19.12	15.54 16.71 17.94 19.12	15.54 16.71 17.94 19.12	15.54 16.71 17.94 19.12	13.96 15.05 16.10 17.15	
BS 1501 ^a 161-Gr 23A 26A 28A	13.74 15.54 16.71	13.74 15.54 16.71	13.74 15.54 16.71	13.74 15.54 16.71	12.37 13.96 15.05		BS 1501 ^a 221-Gr 26B 28B 30B 32B	19.96 21.35 22.85 24.35	19.54 21.05 22.55 24.05	19.12 20.60 22.10 23.60	18.07 19.42 20.75 22.25	15.38 16.57 17.78 18.98	Up to and including 1 1/4 in thick.
BS 1501 ^a 161-Gr 23B 26B 28B	16.72 18.99 20.45	16.28 18.36 19.65	15.53 17.62 18.96	14.19 16.14 17.33	12.40 14.05 15.09	Up to and including 1 1/4 in thick.	BS 1501 ^a 221-Gr 26B 28B 30B 32B	18.81 20.31 21.80 23.15	18.36 19.85 21.20 22.70	18.21 19.56 20.90 22.40	17.32 18.67 20.00 21.35	15.38 16.57 17.78 18.98	Over 1 1/4 in, up to and including 2 1/2 in thick. For over 2 1/2 in thick see material specification.
BS 1501 ^a 211-Gr 26A 28A 30A 32A	15.54 16.71 17.94 19.12	15.54 16.71 17.94 19.12	15.54 16.71 17.94 19.12	15.54 16.71 17.94 19.12	13.96 15.05 16.10 17.15		BS 1501 ^a 224-Gr 26A 28A 30A 32A	15.54 16.71 17.94 19.12	15.54 16.71 17.94 19.12	15.54 16.71 17.94 19.12	15.54 16.71 17.94 19.12	13.96 15.05 16.10 17.15	
BS 1501 ^a 211-Gr 26B 28B 30B 32B	19.96 21.35 22.85 24.35	19.56 21.05 22.55 24.05	19.12 20.60 22.10 23.60	18.07 19.42 20.75 22.25	15.38 16.97 17.78 18.98	Up to and including 1 1/4 in thick.	BS 1501 ^a 224-Gr 26B 28B 30B 32B	20.75 22.40 24.05 25.53	19.56 21.05 22.70 24.30	18.52 20.00 21.35 22.85	16.73 17.93 19.27 20.60	14.94 16.13 17.33 18.37	Up to and including 2 1/2 in thick. For over 2 1/2 in thick see material specification.
BS 1501 ^a 211-Gr 26B 28B 30B 32B	18.81 20.31 21.80 23.15	18.36 19.85 21.20 22.70	18.21 19.56 20.90 21.35	17.32 18.67 20.00 21.35	15.38 16.57 17.78 18.98	Over 1 1/4 in, up to and including 2 1/2 in thick. For over 2 1/2 in thick see material specification.	BS 1501 ^b 620-Gr A B	15.25 17.00	15.25 17.00	15.25 17.00	15.25 17.00	14.55 15.70	

NOTE 1 The nominal design stress values are based on the heat treatment limitations given in the appropriate material specifications. In some cases heat treatment outside these limits may be required. Where this is the case it is essential that due consideration be given to ensure that the properties of the material are not affected to a degree which is unacceptable within the criteria given in 3.3.

NOTE 2 The nominal design stresses for grades “A” of BS 1501 have been derived from typical values.

^a BS 1501, “Steels for fired and unfired pressure vessels. Plates.”

^b BS 1501-6, “Steels for use in the chemical, petroleum and allied industries”.

Table 1C — Nominal design stresses for bars and sections

Specification	Nominal tensile design stress (lbf/in ² × 10 ³) at temperature °C					Notes
	100°	150°	200°	250°	300°	
The range of properties of bars and sections for use in conjunction with Section 2 are not yet available. When the appropriate British Standard is published the values will be inserted in this table. In the meantime nominal design stress values shall be agreed between the manufacturer and the purchaser.						

Table 1D — Nominal design stresses for forgings

Specification	Nominal tensile design stress (lbff/in² × 10³) at temperature °C					Notes
	100°	150°	200°	250°	300°	
BS 1503						
The range of properties for use in conjunction with Section 2 are not given in BS 1503 at present. BS 1503 is being revised to incorporate these properties and when published, the appropriate values will be inserted in this table. Until the revision is published nominal design stress values shall be agreed between the manufacturer and the purchaser.						

Table 1E — Nominal design stresses for pipes

BS ref.	Nominal tensile design stress (lbf/in ² × 10 ³) at temperature °C					Notes
	100°	150°	200°	250°	300°	
BS 3601 ^a						
HFS.22	13.10	13.10	13.10	13.10		
CDS.22	13.10	13.10	13.10	13.10		
ERW.22	13.10	13.10	13.10	13.10		
HFS.27	16.10	16.10	16.10	16.10		
CDS.27	16.10	16.10	16.10	16.10		
ERW.27	16.10	16.10	16.10	16.10		
BS 3602 ^b						
HFS.23	16.14	16.14	16.14	16.14	13.30	
CDS.23	16.14	16.14	16.14	16.14	13.30	
ERW.23	16.14	16.14	16.14	16.14	13.30	
HFS.27	17.33	17.33	17.33	17.33	15.24	
CDS.27	17.33	17.33	17.33	17.33	15.24	
ERW.27	17.33	17.33	17.33	17.33	15.24	
BS 3602 ^b						
HFS.23H	16.14	16.14	16.14	16.14	13.30	
CDS.23H	16.14	16.14	16.14	16.14	13.30	
ERW.23H	16.14	16.14	16.14	16.14	13.30	
HFS.27H	17.33	17.33	17.33	17.33	15.24	
CDS.27H	17.33	17.33	17.33	17.33	15.24	
ERW.27H	17.33	17.33	17.33	17.33	15.24	
BS 3602 ^b						
HFS.23HS	16.14	16.14	16.14	16.14	13.30	
CDS.23HS	16.14	16.14	16.14	16.14	13.30	
HFS.27HS	17.33	17.33	17.33	17.33	15.24	
CDS.27HS	17.33	17.33	17.33	17.33	15.24	
ERW.27HS	17.33	17.33	17.33	17.33	15.24	
BS 3604 ^c						
CD.620	16.50	16.50	16.50	16.50	15.10	
HF.620	16.50	16.50	16.50	16.50	15.10	
CD.621	16.50	16.50	16.50	16.50	15.10	
HF.621	16.50	16.50	16.50	16.50	15.10	
CD.660	21.50	21.50	21.50	21.50	20.00	
HF.660	21.50	21.50	21.50	21.50	20.00	

NOTE 1 The nominal design stress values are based on the heat treatment limitations given in the appropriate material specifications. In some cases heat treatment outside these limits may be required. Where this is the case it is essential that due consideration be given to ensure that the properties of the material are not affected to a degree which is unacceptable within the criteria given in 3.3.

NOTE 2 The nominal design stresses have been derived from typical values for pipes to BS 3601, BS 3602 and BS 3604.

^a BS 3601, "Steel pipes and tubes for pressure purposes. Carbon steel: ordinary duties".

^b BS 3602, "Steel pipes and tubes for pressure purposes. Carbon steel: high duties".

^c BS 3604, "Steel pipes and tubes for pressure purposes: Low and medium alloy steel".

Table 1F — Nominal design stresses for tubes

Specification	Nominal tensile design stress (lbf/in ² × 10 ³) at temperature °C					Notes
	100°	150°	200°	250°	300°	
BS 3059 ^a						
^a BS 3059, “Steel boiler and superheater tubes”. The range of properties for use in conjunction with Section 2 are not given in BS 3059 at present. BS 3059 is being revised to incorporate these properties and, when published, the appropriate values will be inserted in this table. Until the revised BS 3059 is published nominal design stress values shall be agreed between the manufacturer and the purchaser.						

Table 2 — Values of E

Temperature °C	Value of E	
	lbf/in ² × 10 ⁶	kgf/mm ² × 10 ⁶
0	50	.0211
20	29.6	.0208
100	28.66	.0201
200	27.33	.0192
300	26.0	.0183
Intermediate values may be obtained by linear interpolation.		

Section 3. Design

3.1 General

3.1.1 The purchaser shall issue to the manufacturer the design specification for structures covered by this standard which shall specify the normal working conditions of the structure together with such combinations of accident design conditions as the structure is required to withstand. The purchaser shall also specify any corrosion or erosion allowance required in the design and any protective treatment.

The calculation of the pressure, temperature and other loads arising from the specified accident is outside the scope of this document. Attention is, however, drawn to the effect that the volume and design of the containment structure may have on these values.

The design specification shall also state the maximum permissible leak rates on which the design is to be based. The permissible individual component leak rates shall be agreed between the purchaser and the manufacturer.

The design of the structure shall meet the requirements of this section for both the normal design condition and the accident design condition.

3.1.2 The design should be approved on behalf of the manufacturer by a Chartered Engineer with adequate experience of pressure shell design as complying with the requirements of this standard.

The validity of the design shall also be substantiated to the satisfaction of the purchaser by the submission of such drawings, calculations and other data as are necessary to demonstrate compliance with this British Standard. In cases of dispute regarding suitability of the design for pressure loading the manufacturer shall have the option of demonstrating the suitability of the structure by extending the scope of the pressure test (see **5.10**) in a manner to be agreed with the purchaser.

3.1.3 Clause **3.2** “Basic design”, covers the determination of the preliminary scantlings of shells, ends, openings, flanges and tube plates in relation to:

- a) Internal and external pressure loading.
- b) Weight of structure and contents where simple design formulae can be given.

Forms of construction other than those specifically covered in **3.2** are permitted provided that it is demonstrated to the satisfaction of the purchaser by sound analytical methods, experimental techniques or relevant past experience, that they meet the requirements of **3.3**.

3.1.4 Clause **3.3** “Final design appraisal”, lists additional factors which shall be taken into account where relevant. Various modes of failure which have to be considered in relation to these are also listed.

3.1.4.1 The final appraisal shall take into account combinations of the following where relevant:

- Internal and external pressure
- Weight of the structure, contents, attachments, insulation and roof loading in accordance with Appendix A
- External loads imposed by connected equipment
- Local stresses due to supports and other integral attachments
- Stresses due to thermal effects
- Dynamic or shock loads
- Earthquake loading
- Wind and snow loads
- Additional requirements specified by the purchaser.

3.1.4.2 The following modes of failure shall be considered:

- Excessive deformation
- Fatigue
- Wastage by corrosion and/or erosion
- Stress corrosion
- Brittle fracture
- Elastic instability

3.2 Basic design

3.2.1 Shells subject to internal pressure. The following formulae for calculating the thickness of shells are based on the mean diameter membrane theory and do not apply to shells with a thickness exceeding 25 per cent of the internal diameter.

For the purposes of the calculation in **3.2.1.1**, **3.2.1.2**, **3.2.1.3** the following symbols apply and any coherent system of units may be used:

- t = minimum thickness of plates;
- p = design pressure;
- D_i = inside diameter of shell before internal corrosion allowance has been added;
- D_o = outside diameter of shell before the external corrosion allowance has been added;
- f = nominal design stress (from Table 1). This stress may be increased by 10 per cent when considering accident design condition;
- E = modulus of elasticity (from Table 2);

J = joint factor which shall be 1.0 for seamless shells and for joints which are fully radiographed or ultrasonically examined, 0.85 for joints which are not fully radiographed or ultrasonically examined;

c = corrosion allowance (to be specified by the purchaser).

3.2.1.1 Cylindrical shells. The minimum thickness of structures shall be determined by equation (1) or (2):

$$t = \frac{pD_i}{2fJ - p} + c \quad (1)$$

$$t = \frac{pD_o}{2fJ + p} + c \quad (2)$$

3.2.1.2 Spherical shells. The minimum thickness of structures shall be determined by equation (3) or (4):

$$t = \frac{pD_i}{4fJ - p} + c \quad (3)$$

$$t = \frac{pD_o}{4fJ + p} + c \quad (4)$$

3.2.1.3 Combined loadings

a) *Cylindrical shells. Vertical.* For vertical structures the maximum axial membrane stress resulting from the combined effects of internal pressure, and the total weight of the structure, attachments and contents shall be calculated in accordance with equations (5) and (6):

1) Under operating conditions:

$$f \geq \left[\frac{pD_o}{4(t - c)} + \frac{4M}{\pi D_o^2(t - c)} - \frac{W}{\pi D_o(t - c)} \right] \frac{1}{J} \quad (5)$$

NOTE Negative values denote compressive stresses.

2) Under conditions of atmospheric internal pressure:

$$f \geq \left[\frac{4M}{\pi D_o^2(t - c)} + \frac{W}{\pi D_o(t - c)} \right] \frac{1}{J} \quad (6)$$

where:

M = bending moment at the cross-section under consideration due to the weight W

W = total weight at the cross-section under consideration.

The value of maximum axial stress obtained from equation (5) or equation (6) shall not exceed the design stress at design temperature shown in Table 1 and in no case shall the compressive stress, indicated by equation (6), or a negative value of equation (5), exceed the value of

$$0.125E \left(\frac{t - c}{D_o} \right)$$

b) *Cylindrical shells. Horizontal.* For horizontal shells supported at two or more points in their length, the maximum axial membrane stress resulting from internal pressure and bending moment due to the weight of the vessel and its contents, shall be calculated as follows:

1) Under operating conditions:

$$f \geq \left[\frac{pD_o}{4(t - c)} + \frac{4M}{\pi D_o^2(t - c)} \right] \frac{1}{J} \quad (7)$$

2) Under conditions of atmospheric internal pressure:

$$f \geq \left[\frac{4M}{\pi D_o^2(t - c)} \right] \frac{1}{J} \quad (8)$$

The value of maximum axial stress obtained from equation (7) or equation (8) shall not exceed the design stress at design temperatures shown in Table 1, and in no case shall the compressive stress obtained from equation (8) exceed the value of

$$0.125E \left(\frac{t - c}{D_o} \right)$$

3.2.2 Shells subject to external pressure. The rules given herein apply to the design of cylindrical shells with or without stiffening rings and spherical shells, for which the chart, Figure 1, shall be used to determine the minimum shell thickness. The value of the design pressure to be used in calculations shall be not less than the maximum pressure differential that may occur between the outside and inside of the shell in question. The possible influence of steam or vapour condensation should be considered. Superimposed plate stresses resulting from local supports (see 3.1.4.1), should be compensated for, preferably by increasing the shell plate thickness at the supports.

For the purposes of the calculations in 3.2.2.1 to 3.2.2.3 the following symbols apply and any coherent system of units may be used.

t = minimum thickness of cylindrical or spherical shell;

p = design external pressure;

D_o = outside diameter of cylindrical or spherical shell;

- D_s = diameter of the neutral axis of the stiffener;
 R_o = external radius of spherical shell;
 L = effective length of cylindrical shell (see Figure 2);
 L_s = permissible length of shell;
 f = design stress, from Table 3;
 E = modulus of elasticity, from Table 2;
 I = moment of inertia, of stiffening rings;
 c = an allowance for corrosion or erosion, see 3.3.2 d).

3.2.2.1 Cylindrical shells. The minimum thickness of a cylindrical shell under external pressure shall be not less than that determined by the following procedure using the graph in Figure 1. Assume a value for the corroded thickness $(t - c)$ and

determine the ratios $\frac{L}{D_o}$ and $\frac{D_o}{(t - c)}$. Enter the chart,

Figure 1, at the horizontal scale value equal

to $\frac{D_o}{(t - c)}$ and move vertically to the sloping line

representing the value of $\frac{L}{D_o}$.

Move horizontally to the left and read off the value of factor A on the vertical scale. Enter Table 3 with the value of A , read off the design stress corresponding to the design temperature and enter this stress in the expression $p = \frac{2f(t - c)}{D_o}$. If the

value of p so obtained is less than the design value, the chosen value of t must be increased and the

chart re-entered with a new value of $\frac{D_o}{(t - c)}$ such that

the required design pressure is obtained.

NOTE The above procedure is based on the assumption that the value of L is already established. Examples in Appendix D of BS 1500, Part 1⁶⁾ illustrate the procedure to be adopted in the case of an existing shell when it is the value of L that is required.

3.2.2.2 Cylindrical shells with stiffening rings subject to external pressure

a) Intermediate stiffening rings composed of structural shapes continuously welded to the inside or outside of the shell shall be such that, together with a permissible length of shell on each side of the stiffener (see Figure 3), the moment of inertia I of the combined section is not less than:

$$I = \frac{0.18 D_o p L D_s^2}{E} \quad (9)$$

The permissible length L_s of the shells, which may be regarded as effectively contributing to the moment of inertia of the stiffening section, shall be calculated as follows:

$$L_s = 0.75 \sqrt{(t - c) D_o} \quad (10)$$

but in no case shall L_s be taken as greater than L .

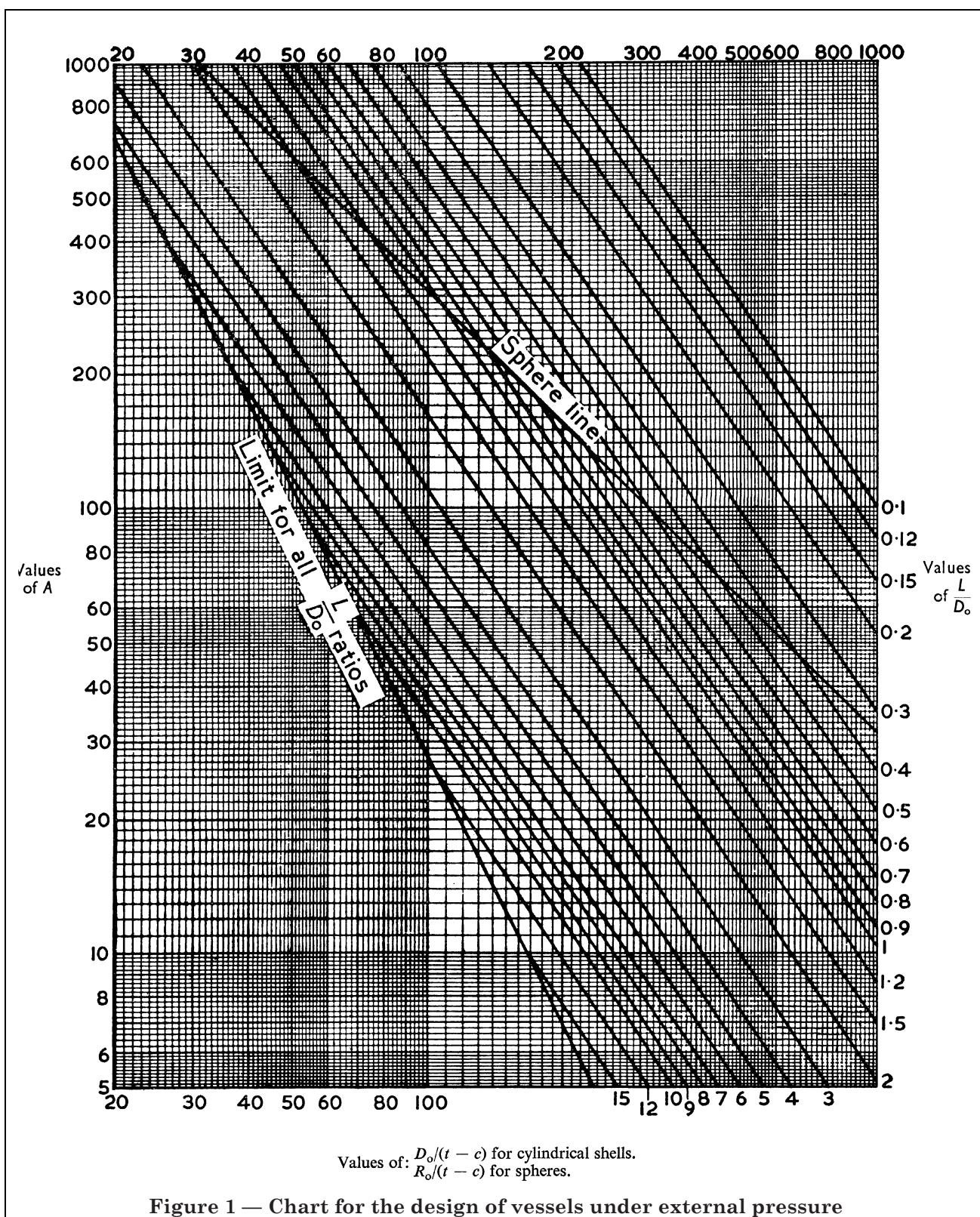
b) Stiffening rings not welded to the shell but fitted inside the structure in close contact with the shell and provided with adequate lateral support shall have a moment of inertia I not less than that required by equation (9). In this case no support by the shell plate shall be taken into account.

c) Stiffening rings shall extend completely around the circumference of the shell and any joints shall be so designed as to develop the full stiffness of the ring.

d) Stiffening rings arranged with local spaces between the shell and ring, as shown in Figure 3, shall be the subject of special consideration, but in no case shall the length of unsupported shell plate exceed the value given in Figure 4.

3.2.2.3 Spherical shells. The minimum thickness of a spherical shell under external pressure shall be not less than that determined by the following procedure using the graph in Figure 1.

⁶⁾ BS 1500, "Fusion welded pressure vessels for use in the chemical, petroleum and allied industries", Part 1, "Carbon and low alloy steels".



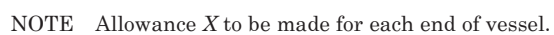


Figure 2 — Effective length of cylinders subject to external pressure

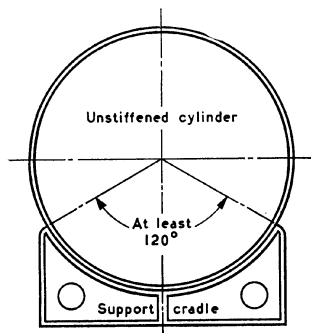


Figure 3a

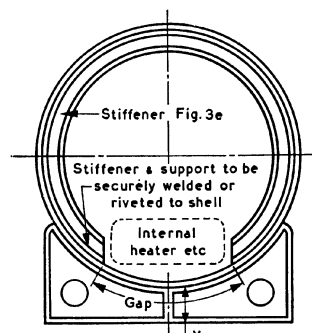


Figure 3b

This type of construction when the gap is greater than length of arc to Figure 4. Moment of inertia of support at X not to be less than I of stiffener.

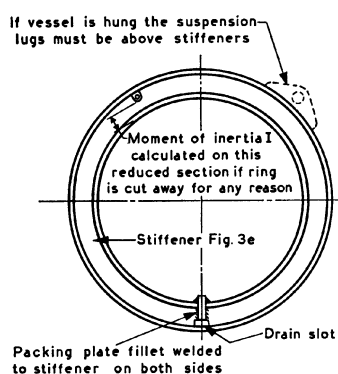


Figure 3c

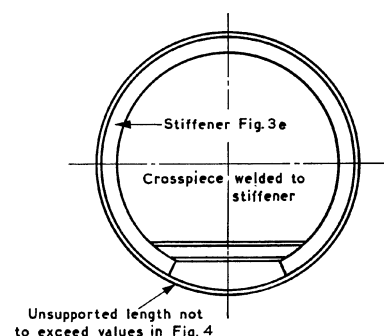


Figure 3d

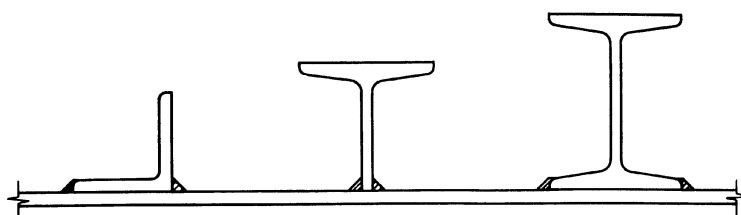


Figure 3e — Typical stiffeners continuously welded to shell

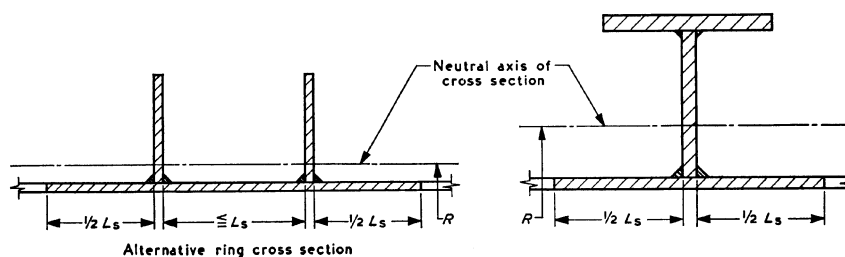


Figure 3f

Figure 3 — Stiffening rings for cylindrical vessels subject to external pressure

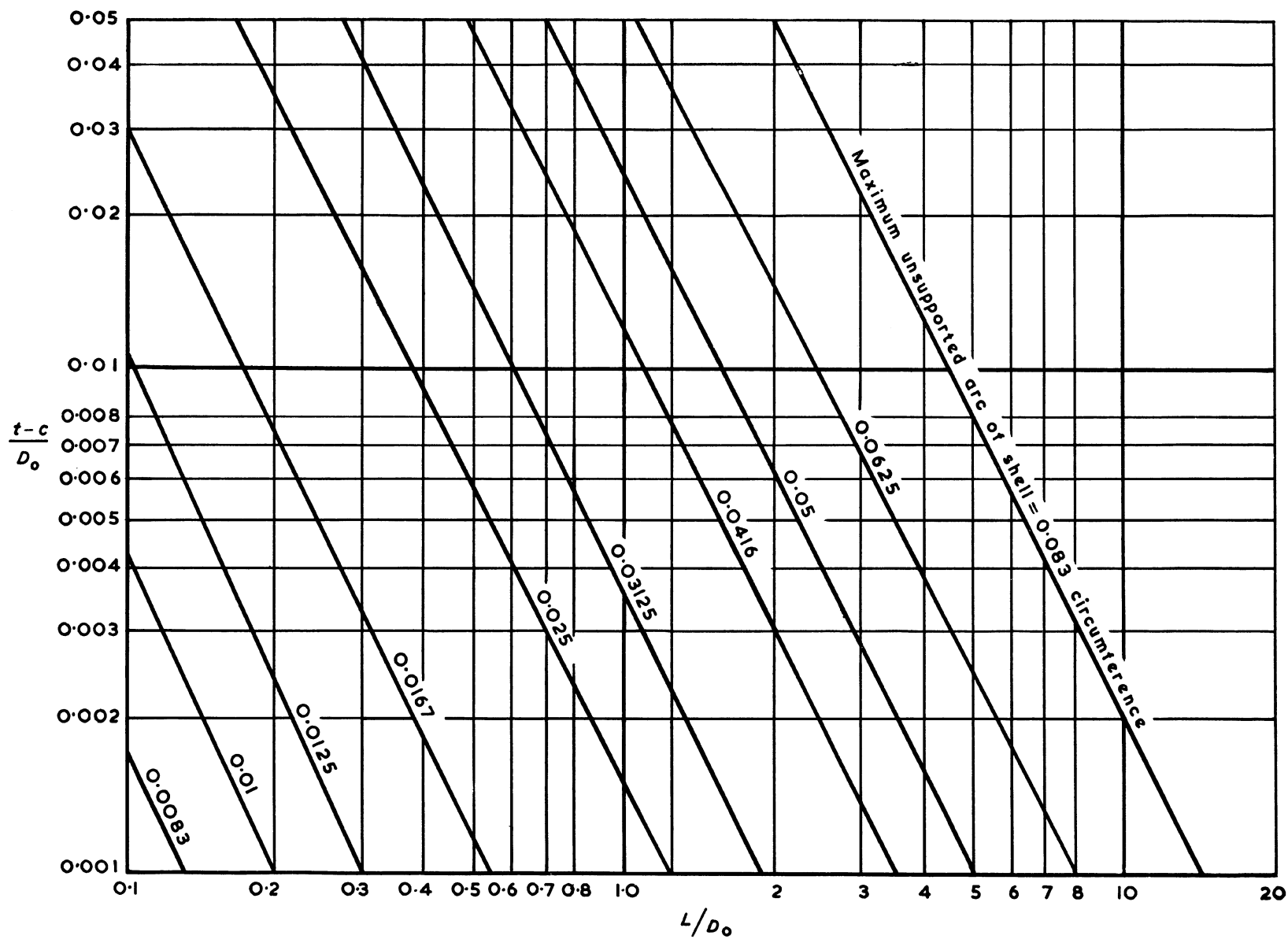


Figure 4 — Maximum permissible arc of shell unsupported by stiffening rings, etc.

Assume a value for corroded thickness $(t - c)$ and determine the ratio $\frac{R_o}{(t - c)}$. Enter the chart,

Figure 1, at the horizontal scale value equal

to $\frac{R_o}{(t - c)}$ and move vertically to the sphere line.

Move horizontally to the left and read off the value of Factor A on the vertical scale. Enter Table 3 with this value of A , read off the design stress corresponding to the design temperature and enter this stress in the expression $p = \frac{2f(t - c)}{R_o}$. If the

value of p so obtained is less than the design value, the chosen value of t must be increased and the chart

re-entered with a new value of $\frac{R_o}{(t - c)}$ such that the required design pressure is obtained.

3.2.2.4 Combined loading

a) Cylindrical shells

i) *Vertical*. For vertical shells subject to external pressure the maximum axial membrane compressive stress, resulting from the combined effects of external pressure and the total weight of the structure, attachments and contents, shall be calculated in accordance with equation (11)

$$f \geq \left[\frac{pD_o}{4(t - c)} + \frac{4M}{\pi D_o^2(t - c)} + \frac{W}{\pi D_o(t - c)} \right] \frac{1}{J} \quad (11)$$

where:

M = bending moment at the cross-section under consideration due to weight W

W = total weight at the cross-section under consideration.

The value of maximum axial stress obtained from equation (11) shall not exceed the design stress at operating temperature taken from Table 1, and in no case shall it exceed the value of

$$0.125E \left(\frac{t - c}{D_o} \right)$$

ii) *Horizontal*. For horizontal shells supported at two or more points on their length, the maximum axial membrane compressive stress resulting from external pressure and bending moment due to the weight of the vessel and its contents, shall be calculated as follows:

$$f \geq \left[\frac{pD_o}{4(t - c)} + \frac{4M}{\pi D_o^2(t - c)} \right] \frac{1}{J} \quad (12)$$

The value of maximum axial stress obtained from equation (12) shall not exceed the design stress at operating temperature taken from Table 1, and in no case shall it exceed the value of

$$0.125E \left(\frac{t - c}{D_o} \right)$$

3.2.3 Flat ends and covers

3.2.3.1 General

- Flat ends and covers shall be designed in accordance with the following equations.
- Figure 5 shows typical flat ends and flat bolted covers, with approved methods of attachment to the shell.

NOTE Other types of flat ends may be used by agreement between manufacturer and purchaser but any significant discontinuity stresses arising therefrom should receive special attention and the value of K used in equation (13b) shall be chosen to limit these stresses to an acceptable value. In general such values of K should be of the order of 3 or 4.

For the calculations required by 3.2.3.2 the following symbols shall apply:

- t = minimum thickness of end anywhere within the gasket inside diameter, inches;
- t_1 = minimum thickness of end anywhere within the cover outside diameter, inches;
- p = design pressure (internal or external), lbf/in²;
- D = diameter of the plate measured as indicated in Figure 5, inches;
- r = knuckle radius as indicated in Figure 5, inches;
- f = design stress, lbf/in², from Table 1. This stress may be increased by 10 per cent when considering accident conditions;
- c = a corrosion allowance as specified by the purchaser;
- G = diameter, inches, at location of gasket reaction (see 3.2.8.4);
- W = design bolt load, lbf, for bolting-up conditions (see 3.2.8.5 c);
- h_G = radial distance from gasket load reaction to the bolt circle, inches;
- K = a constant to be used in equation (13b) only which depends upon method of attachment to shell and is given in Columns 2 and 3, Figure 5c, Figure 5d and Figure 5e.

Table 3 — Values of f (lb f /in ^{2}) for vessels subject to external pressure

Values of factor A from Figure 1															
Design temp.	Up to 100	120	140	160	180	200	200	300	400	500	600	700	800	900	1 000
°F (°C)	Design stress lb f /in ^{2}														
70° (21°)	30A	3 600	4 200	4 800	5 400	6 000	7 000	8 000	9 500	10 600	11 400	12 000	12 200	12 400	12 500
100° (38°)	29.8A	3 600	4 200	4 750	5 350	5 950	6 950	7 950	9 450	10 550	11 350	11 900	12 100	12 300	12 400
200° (91°)	29.3A	3 500	4 100	4 700	5 300	5 850	6 850	7 850	9 300	10 350	11 000	11 500	11 750	11 900	12 000
300° (149°)	28.8A	3 450	4 050	4 600	5 200	5 750	6 700	7 700	9 100	10 100	10 650	11 050	11 300	11 500	11 600
400° (204°)	28.2A	3 400	3 950	4 500	5 100	5 650	6 600	7 500	8 850	9 800	10 300	10 650	10 850	11 000	11 100
500° (260°)	27.4A	3 300	3 850	4 400	4 950	5 500	6 400	7 250	8 500	9 300	9 800	10 050	10 250	10 400	10 500
600° (315°)	26.5A	3 200	3 700	4 250	4 800	5 300	6 200	6 950	8 000	8 800	9 200	9 400	9 600	9 700	9 800

Intermediate values may be interpolated.

3.2.3.2 Determination of thickness. The minimum thickness of flat ends and covers shall be calculated from equations (13a), (13b), (13c) and (13d) according to type (see Figure 5).

For types Figure 5a and Figure 5b:

$$t = \left(\frac{D}{2} - r \right) \sqrt{\frac{p}{f}} + \frac{pr}{2f} + c \quad (13a)$$

For type Figure 5c: $t = D \sqrt{\frac{p}{Kf}} + c \quad (13b)$

For types Figure 5d and Figure 5e

$$t = G \sqrt{\frac{p}{Kf}} + c \quad (13c)$$

and $t_1 = \frac{1.909 Wh_G}{Gf} + c \quad (13d)$

3.2.3.3 Fixings of flat bolted covers. Where bolted covers and ends as in Figure 5c, Figure 5d and Figure 5e are used, the mating flanges and bolt sizes shall comply with 3.2.8.

3.2.4 Conical ends

3.2.4.1 General. Conical ends and conical reducing sections, as shown in Figure 6 shall be designed in accordance with the calculations in 3.2.4.2 and 3.2.4.3.

For the purposes of the calculations in 3.2.4.2 and 3.2.4.3 the following symbols shall apply and any coherent system of units may be used:

- t = minimum thickness of conical section end;
- p = design pressure;
- f = nominal design stress as listed in Table 1. This stress may be increased by 10 per cent when considering accident conditions;

J = Joint factor which shall be 1.00 for seamless shells and for joints which are fully radiographed or ultrasonically examined, 0.85 for joints which are not fully radiographed or ultrasonically examined;

D_c = inside diameter of the conical end or section at the position under consideration, before corrosion allowance is added (see Figure 6);

D_o = outside diameter of the conical end or section at the position under consideration (see Figure 6);

r = inside radius of transition knuckle, which shall be taken as 0.01 D_c in the case of conical sections without knuckle transition;

c = corrosion allowance;

$\alpha_1, \alpha_2, \alpha$ = angle of slope of the conical section (at the point under consideration) to the axis (see Figure 6);

Ψ = difference between angle of slope of two adjoining conical sections (see Figure 6);

K = a factor, taking into account the stress in the knuckle (see Table 4);

L = distance, from knuckle or junction within which meridional stresses determine the required thickness

$$(\text{see Figure 6}), = 0.5 \sqrt{\frac{D_o(t - c)}{\cos \Psi}}$$

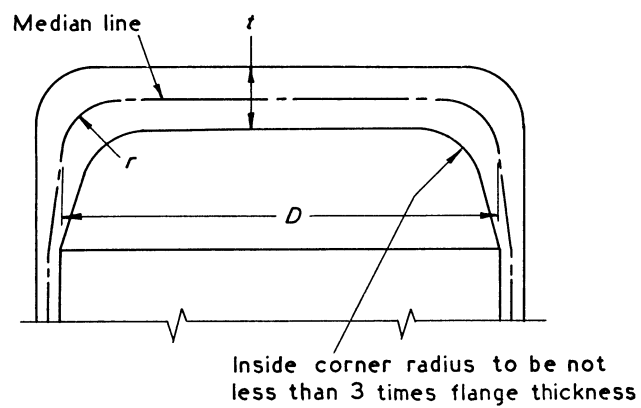


Figure 5a

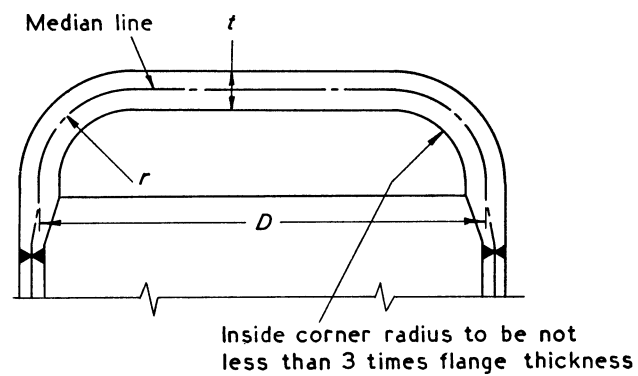


Figure 5b

Figure 5 — Typical flat ends and covers (*continued*)

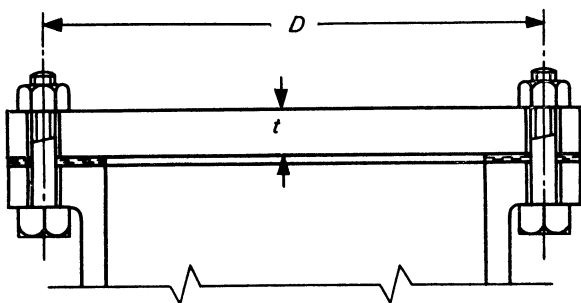
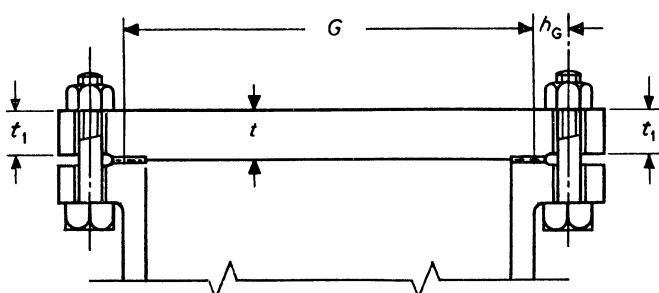
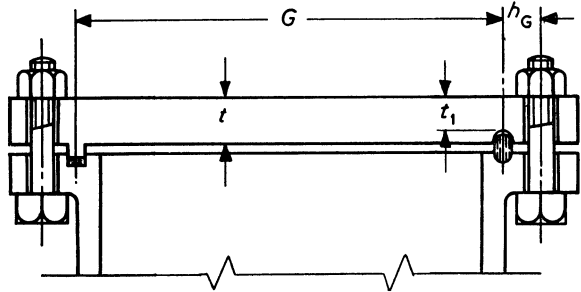
Type	Limitations	K
 Figure 5c	Gasket shall be full width of flange	6.0
 Figure 5d	$K = \frac{1}{\left[0.30 + 1.5 \times \frac{W_{m1} \times h_G}{H \times G} \right]}$ $W_{m1} = \text{minimum required bolt load for operating conditions, lbf}$ $h_G = \text{radial distance from gasket load reaction to the bolt circle in inches}$ $H = \text{total hydrostatic force, lbf}$ $G = \text{diameter at location of gasket reaction in inches}$	
 Figure 5e		

Figure 5 — Typical flat ends and covers (concluded)

3.2.4.2 Conical ends subject to internal pressure

a) *Design method.* The stresses in the knuckle or in the circumferential seam at the wide end of the cone acting in a meridional direction are predominantly bending stresses and the stresses acting in a circumferential direction are predominantly membrane stresses. The design takes into account each of these effects in turn in sub-paragraphs b) and c) below. The greater of the two wall thicknesses so derived governs. For shallow cones, the thickness may be determined by the method in sub-paragraph d), even though the resulting wall thicknesses may be less than those determined under sub-paragraph b) and c).

b) *Thickness of knuckle or conical section at junction.* The thickness of cylinder and conical section within distance *L* from the junction shall be determined by:

$$t = \frac{pD_oK}{2fJ} + c$$

(14a)

If the distance of a circumferential seam from the knuckle or junction is less than *L* then *J* shall be taken as 1.00 otherwise *J* shall be the factor appropriate to the circumferential seam.

c) *Thickness of conical section away from junction.* The thickness of these parts of conical sections not less than distance L away from the junction with a cylinder or other conical sections shall be determined by:

$$t = \left(\frac{pD_e}{2fJ - p} \right) \left(\frac{1}{\cos \alpha} \right) + c \quad (14b)$$

d) *Shallow conical sections.* The thickness of conical sections having an angle of inclination to the vessel of more than 75° shall be determined as for a flat end as prescribed in **3.2.3**.

3.2.4.3 Conical ends subject to external pressure. For a conical end or conical section (frustum) under external pressure, whether the end is of seamless or butt welded construction, the general provisions of sub-paragraphs b), c) and d) above are applicable, except that the thickness shall not be less than as prescribed below:

a) The thickness of a conical end or conical section under external pressure, when the angle of inclination of the conical section (at the point under consideration) to the vessel axis is not more than 75° , shall be made equal to the required thickness of a cylindrical shell, in which the diameter is $D_o/\cos \alpha$ and the effective length is equal to the slant height of the cone on conical section, or slant height between the effective stiffening rings, whichever is less.

b) The thickness of conical ends having an angle of inclination to the vessel axis of more than 75° shall be determined as for a flat cover as prescribed in **3.2.3**.

3.2.4.4 Constructional details. Connections between cylindrical shells and conical sections and ends shall preferably be by means of a knuckle transition radius. Typical permitted details are shown in Figure 6. Alternatively conical sections and ends may be butt welded to cylinders without a knuckle radius when the change in angle of slope Ψ between the two sections under consideration does not exceed 30° .

3.2.5 Domed ends

3.2.5.1 General. Domed ends of hemispherical, semi-ellipsoidal or dished shape shall be designed in accordance with the following formulae. The formulae do not apply when the calculated thickness exceeds 10 per cent of the outside diameter.

a) Limitations of shape.

End plates shall conform to one of the following shapes. (See BS 1966⁷⁾):

- 1) Hemispherical (see Figure 7a).
- 2) Semi-ellipsoidal (see Figure 7b).

The ratio of major axis to minor axis shall not be greater than 2.6 : 1.

- 3) Torispherical (dished and flanged) (see Figure 7c).

i) The inside radius of dishing R_i shall not be greater than the outside diameter D_o .

ii) The inside corner radius r_i shall be not less than 10 per cent of the inside diameter, and not less than $3t$.

iii) The external height h_o shall be not less than $0.18D_o$.

Table 4 — Values of K as a function of Ψ and r_i/D_o

Ψ	Values of K for r_i/D_o ratios of											
	0.01	0.02	0.03	0.04	0.06	0.08	0.10	0.15	0.20	0.30	0.40	0.50
10°	0.70	0.65	0.60	0.60	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
20°	1.00	0.90	0.85	0.80	0.70	0.65	0.60	0.55	0.55	0.55	0.55	0.55
30°	1.35	1.20	1.10	1.00	0.90	0.85	0.80	0.70	0.65	0.55	0.55	0.55
45°	2.05	1.85	1.65	1.50	1.30	1.20	1.10	0.95	0.90	0.70	0.55	0.55
60°	3.20	2.85	2.55	2.35	2.00	1.75	1.60	1.40	1.25	1.00	0.70	0.55
75°	6.80	5.85	5.35	4.75	3.85	3.50	3.15	2.70	2.40	1.55	1.00	0.55

⁷⁾ BS 1966, "Domed ends for tanks and pressure vessels".

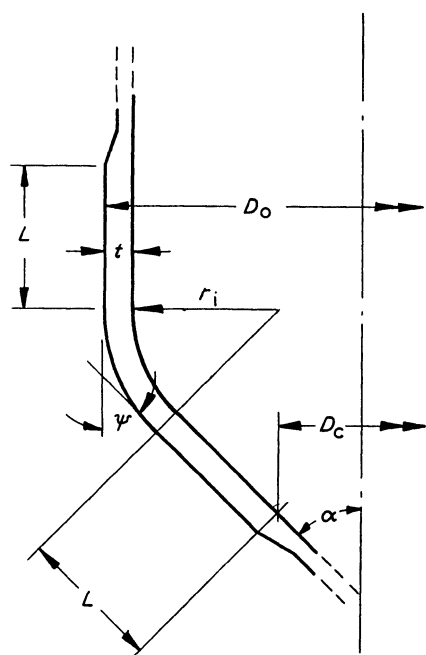


Figure 6a — Cone/cylinder with knuckle

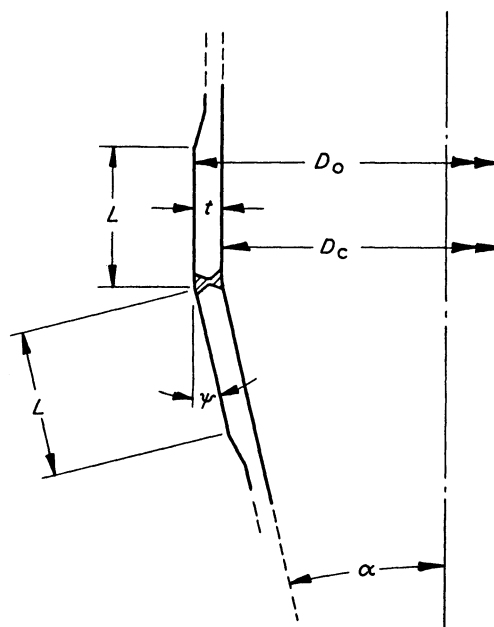


Figure 6b — Cone/cylinder without knuckle

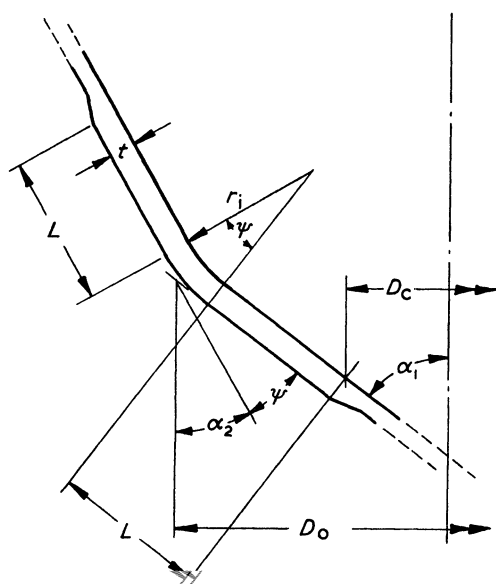


Figure 6c — Cone/cone with knuckle

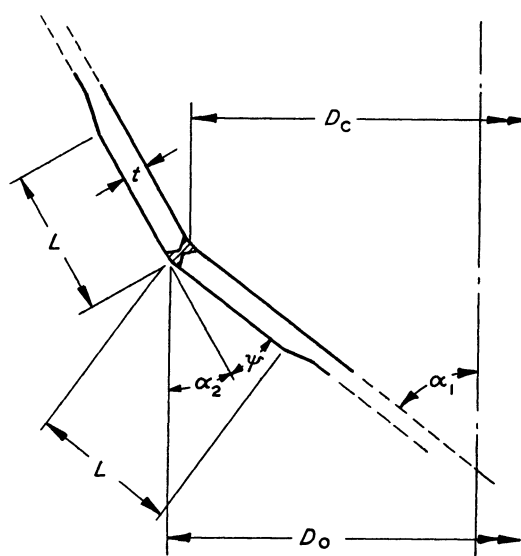


Figure 6d — Cone/cone without knuckle

Figure 6 — Conical ends

b) For the purposes of the calculations in 3.2.5.2 and 3.2.5.3 the following symbols apply and any coherent system of units may be used:

t = minimum thickness of end;

c = allowance for corrosion or erosion;

p = design pressure;

D_i = inside diameter of end before the internal corrosion allowance has been added;

D_o = outside diameter of end before the external corrosion allowance has been added;