

**BS 5387 : 1976**

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Specification for

**Vertical cylindrical welded storage tanks for
low-temperature service: double-wall tanks for
temperatures down to -196°C**

Spécification des récipients de stockage cylindriques verticaux soudés
en acier pour usage à basses températures: Récipients à paroi double
pour les températures jusqu'à -196°C

Spezifikation für senkrechte, zylindrische Lagerbehälter aus
geschweißtem Stahl zur Verwendung bei niedrigen Temperaturen:
Doppelwändige Behälter für Temperaturen bis -196°C

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Foreword

This British Standard is designed to provide industry with tanks of adequate safety and reasonable economy for the storage of liquids in the range -50°C to -196°C , which range includes the following liquefied gases: ethylene, ethane, methane (natural gas), oxygen and nitrogen.

The tanks covered by this standard are of the double-wall type, the inner tank containing the refrigerated product and the outer tank containing the insulation. A range of materials is proposed for the construction of the inner tank: aluminium alloys, austenitic steels and 9 % nickel steel. In the ranges of thicknesses and design metal temperatures permitted by this standard, these materials are not considered to be susceptible to brittle fracture.

However, attention is drawn to the possibility of fast fractures in thick sections and it may be necessary to undertake extensive fracture mechanics tests in order to establish the suitability of the materials in thicknesses exceeding those specified in this standard.

Ferritic steels are proposed for the construction of the outer tank and the requirements of this standard have been drawn largely from BS 2654 and BS 4741. It must be emphasized that the outer tank is not designed for containing any liquid.

Whilst the experience of the committee in formulating standards for ambient temperature storage tanks (BS 2654) and tanks for operation down to -50°C (BS 4741) has been used in the preparation of this standard, attention is drawn to an important difference between this standard and the two former standards; namely that there is no certainty that the weld metal strength will 'over-match' the plate strength. This fact therefore necessitates designing on the minimum strength of the weakest material in the construction, which may, in some circumstances, be the weld metal. As the design stress is based primarily on a fraction of the yield (or proof) strength of the material, it has been necessary to formulate new rules for assessing the yield characteristics of the weld metal under stress. However, it is to be hoped that eventually new materials and consumables suitable for use with this standard will be developed to ensure over-matching at all times and to make the problem of the assessment of joint strength as straightforward as it is for ferritic steels.

Users of this British Standard are reminded that the BSI committee responsible for its contents are prepared to offer interpretations of the text, on request.

British Standard Specification for

Vertical cylindrical welded storage tanks for low-temperature service: double-wall tanks for temperatures down to -196°C

Section one. General

1. Scope

This British Standard relates to the design, material selection, fabrication, erection and testing requirements for flat-bottomed double-wall vertical cylindrical tanks of welded construction for above-ground installation at service temperatures down to -196°C .

The composite tank contains the liquid to be stored at a temperature equal to or just above its boiling point at atmospheric pressure and comprises an inner tank holding the liquid which is entirely surrounded by insulation retained within an outer mild steel tank of the same form but larger than the inner tank by the thickness of insulation.

The outer tank is designed for ambient conditions as an envelope to retain the insulation and purge gas and to prevent at all times the ingress of airborne moisture. When there is a suspended ceiling on the inner tank, the outer tank is further designed as a gasholder to contain the vapour pressure of the liquid contents.

A suspended deck permits free passage of gas between the vapour space of the inner tank and the outer tank, whereas a fixed metal roof on the inner tank will provide a complete barrier for both liquid and vapour between the inner and the outer tanks, and the outer tank may therefore be purged with inert gas if desired. The outer tank is not designed for storage of the inner tank liquid under any circumstances.

A suspended deck is non-preferred in tanks for the storage of liquid oxygen.

2. References

The titles of the standards publications referred to in this standard are listed on the inside back cover.

3. Design conditions

Tanks shall be designed to suit the pressure and vacuum that will be required in service but shall not exceed 140 mbar* gauge internal pressure nor 6 mbar gauge internal vacuum. The lowest design metal temperature permitted in the use of this standard shall be -196°C . Specific conditions for outer and inner tanks are given in clauses 7 and 13 respectively.

NOTE. For pressures or vacua outside the range stated above see appendix D.

* 1 mbar = 10^2 N/m^2 = 100 Pa.

† The attention of the purchaser is drawn to the desirability of considering tank design, insulation and foundation design together to give the most economical arrangement (see appendix A). It is recommended that the design of foundations be agreed between purchaser and tank designer at the time of ordering.

4. Information to be supplied by the purchaser

The following information shall be supplied by the purchaser in his enquiry.

- (a) Geographical location of the tank.
 - (b) Diameter and height, or the capacity, of the inner tank, including ullage. Where only capacity of the tank is specified, the permissible ground loading conditions shall be included.†
 - (c) All relevant properties of the contained fluid, including the specific gravity, corrosion allowance (if required) and permissible boil off.
 - (d) The design vapour-pressure and vacuum conditions for both the inner and outer tank.
 - (e) The number of thermal cycles and their magnitudes.
 - (f) The minimum and maximum design temperatures for the inner and outer tank.
 - (g) The size, number and type of all mountings required, showing locations.
- NOTE. The attention of the purchaser is drawn to the desirability of minimizing the number of connections required into the bottom courses of the inner tank shell.
- (h) Details of flange drillings, if any, in accordance with BS 1560.
 - (i) Details of painting and surface preparation requirements.
 - (j) The demarcation of responsibility between the designer, the manufacturer and the erector of the tank when these are not the same.
 - (k) The method of despatching tank plates for export.
 - (l) Whether welding electrodes, special welding equipment, welding procedures or key plating equipment are to be supplied by the tank manufacturer.
 - (m) Other relevant standards or specifications.
 - (n) Whether the tank manufacturer is to include in his supply a tank nameplate and, if required, the details to be included on the nameplate.
 - (o) Whether a tank log book is required and, if required, the contents of the log book.

5. Information to be assumed if not otherwise agreed or specified by purchaser or manufacturer

- 5.1 Materials used will be in accordance with the appropriate specification listed in this standard, except as modified or amplified by the provisions of this standard (see 6.1).
- 5.2 There will be no deleterious external loading or movement from piping, etc. See 7.3(h).
- 5.3 Seismic loads will not be included (see 7.5).
- 5.4 Outer tanks with lowest shell course not exceeding 10 mm thick will have no ring of annular plates (see 8.1.2).
- 5.5 The roof slope will be 1 in 5 (see 10.2.1).
- 5.6 Radius of curvature of a dome roof will be 1.5 times the diameter of the tank (see 10.2.2).
- 5.7 Purlin spacing will not be increased (see 10.3.3).
- 5.8 Weld details for nozzles, manholes and other openings will be limited to those shown in figures 13 to 21 (see 11.6.1. and 17.5).
- 5.9 Flanges of all nozzles and manholes will be made and drilled in accordance with the requirements for class 150 given in BS 1560 : Part 2 (see 11.8 and 17.7).
- 5.10 All materials used in the manufacture of the inner tank will be to this specification (see 12.1).
- 5.11 No alternative design temperature will be used (see 19.2.8).
- 5.12 There will be no stop valves or cocks installed in the inlet of the relief valves (see 20.2.5).
- 5.13 The relief system will be capable of relieving the flow capacity for the largest single contingency. (see 20.5.2).
- 5.14 Shearing for any other material will not be used (see 22.4.1).
- 5.15 Shop painting for all materials will be as specified in 22.7 (see 22.7.1 and 22.7.2).
- 5.16 Erection marks will be consistent with the manufacturer's normal practice (see 22.8.1 and 22.8.2).
- 5.17 Site erection equipment, labour, false work, etc. will be supplied by the erection contractor (see 23.1).
- 5.18 The erection contractor will decide the method for the protection of the shell against wind damage during erection (see 23.8).
- 5.19 Roofs will not be erected on the tank bottom and raised into position by air pressure or other means (see 23.9).
- 5.20 The welding processes used will be as limited by this standard (see 24.1.2.).
- 5.21 Additional tests will be required (see 24.1.3).
- 5.22 The sequence in which the joints are to be welded will be to the erection contractor's normal practice (see 24.2.).
- 5.23 Previously qualified welding procedures and welders will be acceptable (see 25.1.4).
- 5.24 Welders for 9 % Ni and stainless steels may be qualified using carbon steel plate (see 25.2.1).

5.25 The length of the procedure test weld and the dimensions of the parent plate will be not less than that required to give a minimum of 300 mm of weld material meeting the requirements of this standard (see 25.2.2).

5.26 The test load on the foundation of the base insulation will not be less than 110 % of the product design load (see 27.2.2.3(b)).

Section two. Outer tanks

6. Outer tank materials

6.1 **Specifications.** The requirements for material selection for outer tanks defined in this section are based on the design metal temperature for the outer tank shell, bottom, roof, etc., being not less than ambient temperature.

All materials used in the manufacture of tanks to this standard shall be in accordance with the appropriate specifications listed except as modified or amplified by the provisions of this standard.

This shall not preclude the use of otherwise suitable materials* where so agreed between purchaser and manufacturer provided that the materials are equivalent in heat treatment and chemical composition to those listed below and in other respects meet all the requirements of this standard.

Plates, sections and bars:	in accordance with BS 4360.
Forgings only:	in accordance with BS 1503 (carbon and carbon manganese steels).
Bolting material:	in accordance with BS 1506.
Piping:	in accordance with BS 3602, BS 3603.

6.2 **Steelmaking process.** Steels shall be made by the open-hearth, electric-furnace or top-oxygen-blown process. Bessemer steels shall not be used. Semikilled or fully killed steel may be used provided that all the requirements of this standard are met. Rimmed steel shall not be used.

6.3 Chemical composition

6.3.1 The carbon equivalent calculated from the ladle analysis using the formula:

$$C_{ev} = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Ni + Cu}{15}$$

shall not exceed 0.43 % for plates 20 mm thick up to and including 25 mm or 0.42 % for plates thicker than 25 mm.

6.3.2 All material such as forgings or piping that will be welded to the outer tank should have a carbon content less than 0.25 %.

6.4 Notch ductility

6.4.1 Except as detailed in table 1 and 6.4.3, all parts of the tank shall be impact tested at a temperature determined from:

- (a) figure 1,
- (b) ruling thickness of the part under consideration, and

* Examples:

- Plates, sections and bars in accordance with ISO/R 630;
- Forgings in accordance with ASTM A105;
- Piping in accordance with ASTM A106 grade B, ASTM A524, API 5L grades A and B.

(c) the design metal temperature (0°C for service in the United Kingdom)*.

The impact test, when required, shall be at a temperature not higher (warmer) than the temperatures specified in table 1.

6.4.2 Reinforcing plates. The notch ductility of reinforcing plates shall be determined by reference to their maximum thickness and to figure 1. If the plates are more than 40 mm thick, the steel shall be impact tested at -50°C and have an impact value not less than 27 J.

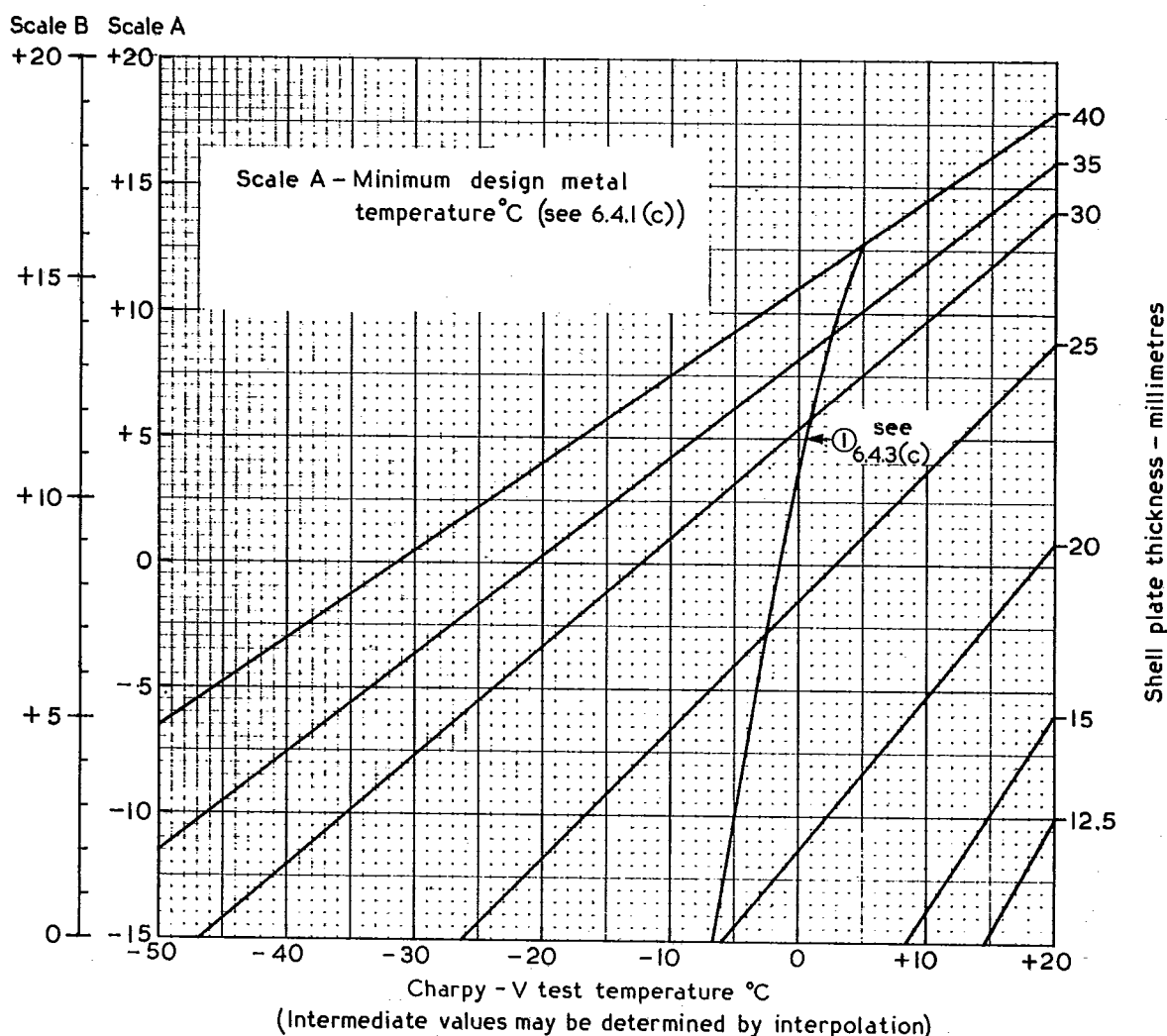
6.4.3 Waiving of impact tests. Impact tests are not required as part of the specification:

- (a) for items less than or equal to 12.5 mm thick in material grades up to and including grade 50;
- (b) for items that have a design metal temperature of $+10^{\circ}\text{C}$ or higher, are less than 25 mm thick, and are

Table 1. Highest temperatures for impact testing

Steel grade (Gr)	Thickness (t) (mm)	Highest test temperature ($^{\circ}\text{C}$)	Minimum † impact value (J)
$\text{Gr} \leq 43$	$t \leq 12.5$	No test required	
$\text{Gr} \leq 43$	$t > 12.5$	+20	27
$43 < \text{Gr} \leq 50$	$t \leq 12.5$	No test required	
$43 < \text{Gr} \leq 50$	$t > 12.5$	- 5	41
$\text{Gr} > 50$	All	-15	41

† The above impact values are the minimum average of three specimens. The minimum individual value shall not be less than 75 % of the minimum average values.



NOTE. Scale A on the ordinate is to be used in determining minimum Charpy-V requirements for the thickness and minimum design temperature concerned. For the purposes of this note, conversion of the measured impact value to the 27 J (or 41 J for steels stronger than grade 43) value may be made on the basis of 1.35 J per $^{\circ}\text{C}$; such extrapolation shall be limited to a maximum range of 20°C . For example if the actual value by test is 33.75 J at -20°C for a grade 40D steel, the equivalent test temperature for 27 J may be assumed to be -25°C .

Figure 1. Minimum Charpy-V impact requirements for shell plates (see also 6.4.3)

* The outer tank has very low tensile stresses and also, from an operating temperature point of view, it is similar to an empty BS 2654 oil-storage tank. In addition the roof-shell compression areas are prestressed prior to operation, during the roof testing. Hence, it is permissible to use the BS 2654 relationship between thickness and impact test temperature. For areas outside the United Kingdom, the design metal temperature shall be the lowest daily mean temperature (0.5 (maximum temperature plus minimum temperature)).

made from steel that is weaker or equal to grade 43 and has a specified minimum yield stress not exceeding 300 N/mm^2 ;

(c) for all items that have a reference thickness/minimum design temperature to the right of curve 1 on figure 1, and are made of steel having a normalized structure and a specified minimum tensile strength less than 460 N/mm^2 for which the specified minimum manganese content divided by the specified maximum carbon content is not less than 4.0;

(d) for all items on which the stress is either compressive or less than 46 N/mm^2 tensile.

6.4.4 Reference thickness. Permanent attachments, reinforcing plates, nozzle bodies and structural items shall be taken as having a reference thickness equal to their maximum thickness.

Nozzle flanges shall be taken as having a reference thickness that is either the thickness of the branch to which the flange is attached or 25 % of the flange thickness, whichever is the greater.

6.5 Mountings. Reinforcing plates and insert plates shall have a minimum specified yield strength not less than 90 % of the minimum specified for the shell plates to which they are attached. Nozzle bodies shall also meet these requirements when the nozzle body is used in the reinforcement calculation.

6.6 Other requirements

6.6.1 It is recommended that, when purchasing steel for this application to the requirements of ISO/R 630, reference be made to the appropriate national steel standard for the purpose of specifying additional requirements not included in ISO/R 630, e.g. dimensional tolerances, etc.

6.6.2 The measured edge thickness underrun of the calculated, minimum or nominal thickness of any plate shall not be greater than half the specified percentage rolling tolerance figures permitted in table 4 of BS 4360 : 1972.

7. Outer tank loadings

7.1 General. The outer tank shall be designed to contain the insulation surrounding the inner tank and either the inert purge gas or, in the case of suspended roof designs, vaporized product.

The outer tank shall not contain liquid.

It is important to consider all possible loads at the design stage, in view of the fact that the shell thickness will be less than that required for a similar tank designed to contain a liquid.

The outer tank shall be designed for the most severe possible combination of the loads specified in 7.2 to 7.5.

7.2 Bottom loads. The loads acting on the outer tank bottom are the total superimposed loads due to the product, the inner tank weight, the outer tank weight and the insulation weight and are transferred directly to the foundations because the tank bottom is acting as a fully supported membrane.

7.3 Shell loads. In the design of the shell account shall be taken of the following loads.

(a) Wind loads. The windspeed used in the calculations shall be the maximum 3-second gust estimated to be exceeded on the average only once in 50 years. In the United Kingdom this value shall be taken as 'design wind

speed' as defined in CP 3 : Chapter V : Part 2. In other areas the 3-second gust speed shall be obtained from the appropriate authority.

(b) Design pressure.

(c) Design vacuum.

(d) Insulation weight.

(e) Insulation pressure.

(f) Weight of shell above the point under consideration (temporary and/or permanent).

(g) Loads from roof.

(h) Pipes, valves and other items connected to the outer tank shell shall preferably be designed in such a manner that no significant additional loads or moments are applied to the tank shell. Settlement of the foundations shall be taken into consideration. Where such loads or moments are unavoidable, the purchaser shall advise the manufacturer of their nature and magnitude and the design shall therefore be a matter for agreement between purchaser and manufacturer.

7.4 Roof loads. The design of the outer tank roof shall take into account the following loads:

(a) the weight of the roof and supporting structure plus a minimum superimposed load of 1.2 kN/m^2 of projected area, which includes vacuum, snow and live loads;

(b) the weight of the suspended roof and its insulation and its supporting structure, where applicable;

(c) design pressure;

(d) wind loads, see 7.3.(a);

(e) loads imposed by external or internal connections.

7.5 Seismic loads (where applicable). The design of tanks to withstand seismic loads requires specialist consideration and the methods to be used in such an analysis shall be agreed between purchaser and manufacturer.

8. Outer tank bottom design

8.1 General

8.1.1 The tank bottom should be fully supported by the foundation; recommendations for the construction of the foundations are given in appendix A.

8.1.2 Tanks with bottom shell course not exceeding 10 mm thick shall be constructed from rectangular plates, with sketch plates to the perimeter, or may have a ring of annular plates if so specified by the purchaser.

The minimum thickness of the rectangular, sketch and annular plates shall be 6 mm and the minimum leg length of a sketch plate shall be 500 mm.

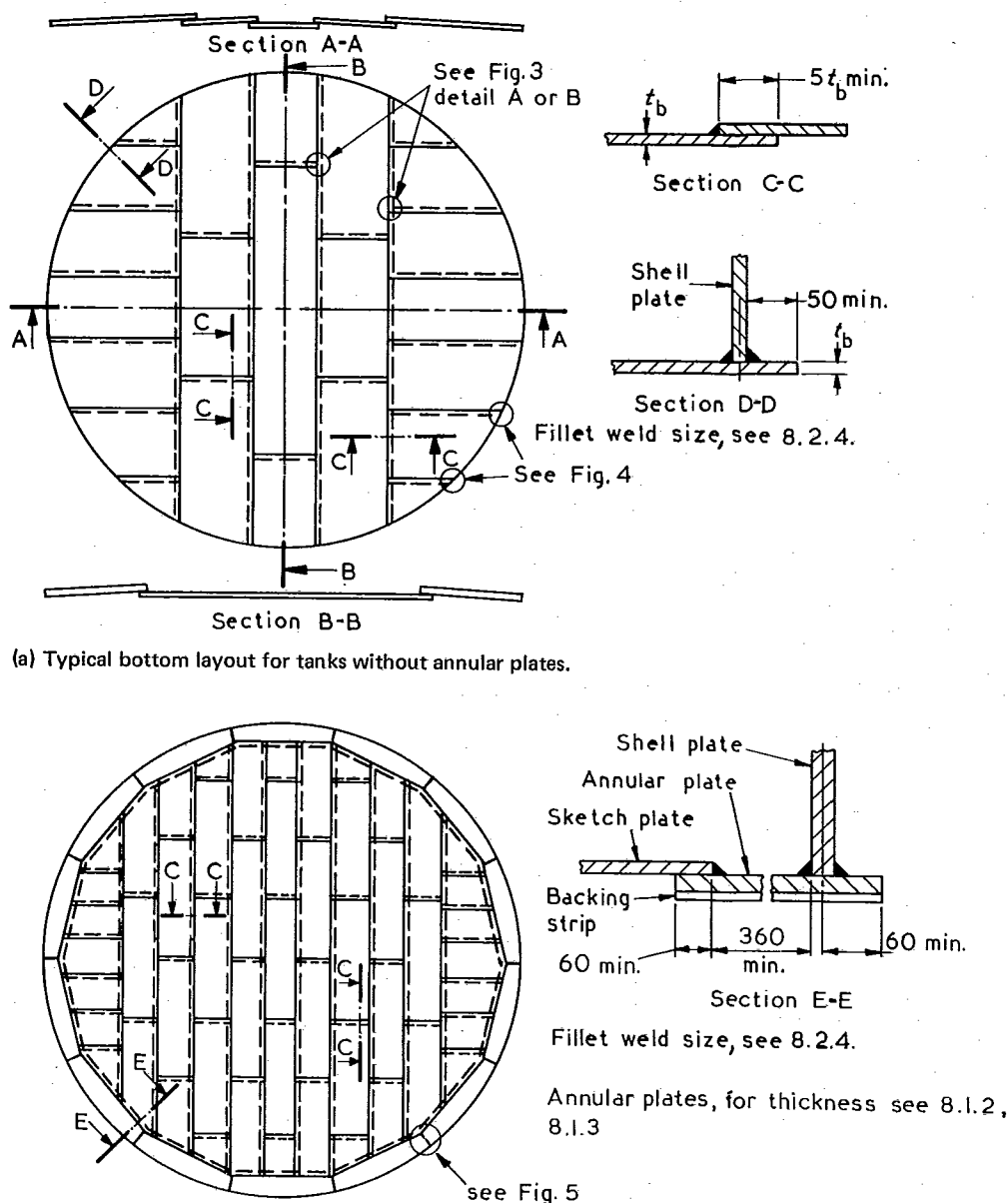
8.1.3 All tanks with a bottom shell course more than 10 mm thick shall have a ring of butt-welded annular plates 8 mm thick, minimum.

8.1.4 The minimum distance between any three-plate joints shall be 300 mm.

8.1.5 Annular plates shall have a minimum width of 500 mm.

8.1.6 The minimum distance from the toe of the outer fillet weld to the outer edge of the bottom plates shall be 25 mm (see also figure 2, details D-D and E-E).

8.1.7 It is recommended that the bottom of the outer tank should be coned up.



(a) Typical bottom layout for tanks without annular plates.

(b) Typical bottom layout for tanks with annular plates.
Lay of plates similar to section A-A and B-B; see (a) above.
All dimensions in millimetres unless otherwise stated.

Figure 2. Typical bottom layouts for tanks (see clauses 8 and 14)

8.2 Bottom design

8.2.1 All joints in rectangular and sketch plates shall be lapped. They shall be welded on the top side only with a full fillet weld, and with a minimum lap of five times the thickness of the plate (see figure 2, detail C-C).

The rectangular plates and the sketch plates shall be lapped over the annular ring of segmental plates where these are used. They shall be welded on the top side only with a full fillet weld and the minimum lap shall be 60 mm (see figure 2, detail E-E).

At the ends of cross joints in rectangular plates and sketch plates where three thicknesses occur, the upper plate shall be hammered down and welded as indicated in figure 3, detail A or B.

8.2.2 For tanks where annular plates are not used, the ends of the joints in the sketch plates under the bottom course of shell plates shall be welded for a minimum distance of 150 mm as shown in figure 4.

8.2.3 For tanks where annular plates are used, the radial seams connecting the ends of the annular segmental plates shall be butt welded with a backing strip the minimum thickness of which shall be 5 mm. An acceptable form of joint is shown in detail F-F on figure 5.

8.2.4 The attachment between the bottom edge of the lowest course of shell plates and the bottom sketch plate or annular plate shall be fillet welded continuously on both sides of the shell plate.

The leg length of both fillet welds shall be equal to the thickness of the shell plate, sketch plate or annular plate (see figure 2, sections D-D and E-E), whichever is the lesser.

Typical layouts for tank bottom plates are shown in figure 2(a), sections A-A and B-B.

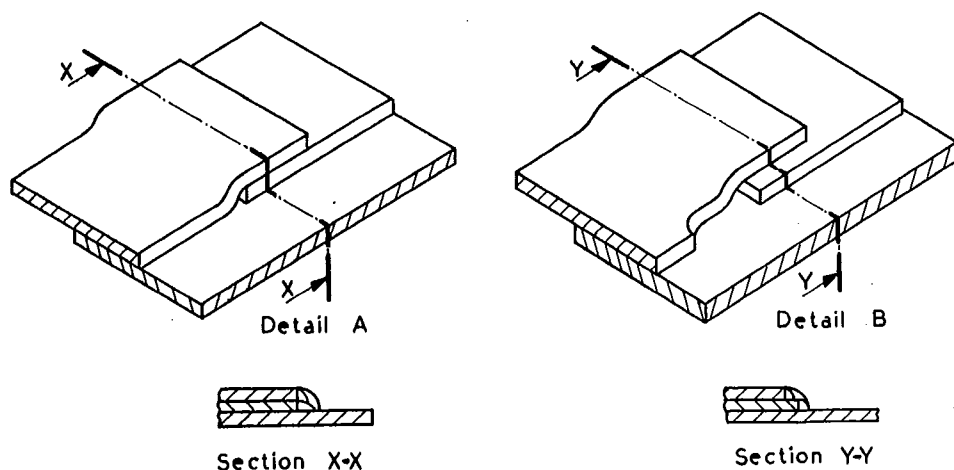
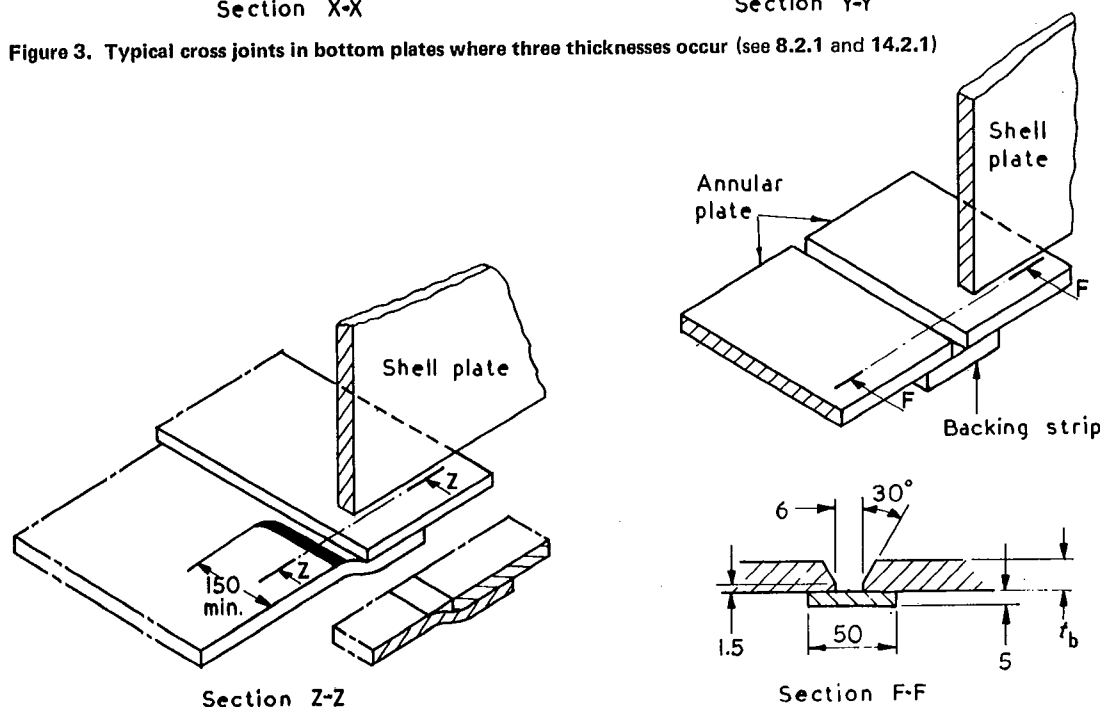
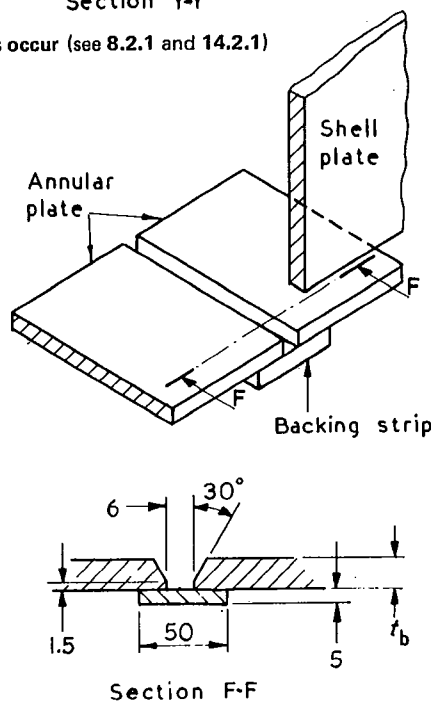


Figure 3. Typical cross joints in bottom plates where three thicknesses occur (see 8.2.1 and 14.2.1)



Dimensions in millimetres.

Figure 4. Typical joints in sketch plates under shell plates; tanks without annular plates (see 8.2.2)



All dimensions in millimetres unless otherwise stated.

Figure 5. Typical annular plate joints under shell plates; tanks with annular plates (see 8.2.3 and 14.2.2)

9. Outer tank shell design

9.1 Shell design stresses

9.1.1 The maximum allowable design stress in any plate before applying the factor η for efficiency of joint shall be the lesser of 260 N/mm² or two-thirds of the material minimum yield strength (N/mm²) at room temperature for all tank courses.

9.1.2 In calculating the thickness of plate required, the joint efficiency factor η shall be taken as 1.0 for butt-welded constructions and 0.65 for double-lap-welded constructions, provided that no relaxation is permitted in the requirements of this standard with regard to the qualification of procedures and operators (see clause 25) and the site inspection of shell joints. Single-fillet-welded shell seams are not permitted.

9.1.3 In no case shall the nominal thickness of shell plates be less than the following:

Nominal tank diameter (D)	Nominal shell thickness
m	mm
$D < 15$	5
$15 \leq D < 36$	6
$36 \leq D \leq 60$	8
$60 < D \leq 75$	10
$D > 75$	12.5

These requirements for minimum nominal thickness are needed for construction purposes and therefore may include any corrosion allowance provided that the shell is shown by calculation to be safe in the corroded condition and in accordance with the requirements of 9.2.

9.1.4 The maximum thickness of shell plates shall be 40 mm.

9.2 Shell thickness calculations

9.2.1 The forces in the outer tank shell shall be computed taking into account the most severe possible combination of loadings specified in 7.3.

9.2.2 The following formula shall be used in calculating the minimum thickness of shell plates:

$$t = \frac{pD}{20 S \eta}$$

where

t is the calculated shell plate thickness (in mm)

p is the internal pressure, this being a combination of internal gas pressure plus insulation pressure (in mbar)

S is the allowable design stress (in N/mm²)

D is the tank diameter (in m)

η is the joint efficiency factor

9.2.3 Since the outer-tank shell thickness computed using the formula in 9.2.2 will generally be significantly less than that for a tank designed to contain a liquid, the design of the shell shall be checked to ensure that it is capable of withstanding the axial compressive loads resulting from the roof weight, shell self-weight, snow load, vacuum, live load, loads transmitted to the shell from loose-fill insulation, wind and seismic loads.

The maximum allowable compressive stress in the outer shell due to vertical compressive forces shall be assessed at each horizontal welded seam and shall not exceed the value of S_c calculated in accordance with the formula:

$$S_c = 12.5 \frac{(t-c)}{R} \times G \eta$$

where

S_c is the allowable compressive stress (in N/mm²)

t is the shell plate thickness at the point under consideration (in mm)

c is the corrosion allowance, if applicable

R is the radius of tank (in m)

G is the factor for increase of allowable stress, see 9.2.4

η is the joint efficiency factor

9.2.4 The formula for calculation of plate thickness is given in 9.2.2 and requires a course-by-course calculation with the design weight, plate thickness and design stress varying from the top to the bottom of the tank.

In addition, the design stress varies with different loading combinations and the design must take into account the different values of factor G for different loading combinations as follows:

Loading combinations	G
(a) Dead weight above point under consideration + insulation + 50 % pipe loads + superimposed load (see 7.4.1)	1
(b) Dead weight above point under consideration + insulation + pipe loads + wind load + 50 % of superimposed load (see 7.4.1)	1.25
(c) Dead weight above point under consideration + insulation + pipe loads + earthquake load + 50 % of superimposed load (see 7.4.1)	1.33

9.3 Wind and vacuum loading

9.3.1 *Primary wind girders.* Self-supporting fixed-roof tanks with roof structures are considered to be adequately stiffened at the top of the shell by the roof structure; a primary ring stiffener is not therefore considered necessary.

9.3.2 Secondary wind girders

9.3.2.1 Fixed-roof tank shells designed in accordance with this standard may require secondary rings to maintain roundness over the full height of the tank shell under wind and/or vacuum conditions of loadings.

9.3.2.2 Secondary rings are not required to carry panel loading but are necessary to prevent preferential local buckling of the tank shell. The size of secondary rings has not been related to the design loads and shall be determined, with respect to tank diameter, in accordance with the table given in figure 6.

The fixing of such secondary rings shall be in accordance with figure 6.

9.3.2.3 The vertical positioning of secondary rings shall be calculated by first determining the height of a complete tank shell of equivalent stability, at the same diameter, and of the same thickness as the top course of shell plating. An analysis of this equivalent tank shell in association with the required wind and vacuum design criteria will determine the number of secondary rings required. In many cases these rings will be located on the top course, or on a course of similar thickness, but if the location is not on such courses the actual positioning shall be determined by converting back the equivalent shell course heights to their actual values. The full analysis is best illustrated by way of an example in 9.3.3. A secondary ring shall not be located within 150 mm of a main circumferential tank seam.

9.3.2.4 The wind speed used in calculation shall be that defined in 7.3(a).

9.3.2.5 The design vacuum shall be taken as 6 mbar irrespective of the design wind speed (i.e. 2.5 mbar setting plus 3.5 mbar to allow accumulation for the vacuum valves to develop design throughput).

9.3.2.6 The formulae to be used in the design of secondary wind girders shall be as follows:

$$H_e = h \sqrt{\left(\frac{t_{\min}}{t}\right)^5}$$

$$H_E = \Sigma H_e$$

$$K = \frac{95\,000}{3.563V_w^2 + 580V_a}$$

$$H_D = K \sqrt{\left(\frac{t_{\min}^5}{D^3}\right)}$$

where

D is the tank diameter (in m)

$t_{\min}$ is the thickness of the top course (in mm)

t is the thickness of each course in turn (in mm)

h is the height of each course in turn below any primary ring (in m)

H_e is the equivalent stable height of each course at $t_{\min}$ (in m)

H_E is the equivalent stable full shell height at $t_{\min}$ (in m)

- V_w is the design wind speed (in m/s)
 V_a is the vacuum for design of secondary wind girders (in mbar)
 K is a factor
 H_p is the maximum permitted spacing of rings on shells of minimum thickness (in m)

9.3.3 Example. A fixed-roof tank 48 m in diameter, 35 m high and having fourteen 2.5 m courses of thickness 9.0, 9.0, 9.0, 9.5, 9.5, 9.5, 10.0, 10.0, 10.5, 11.0, 11.0, 11.5, 11.5 and 11.5 mm is to be designed for a wind speed of 55 m/s. How many secondary rings are required, and what is their location and size?

Course	h	t	H_e
1	2.5	9.0	2.5
2	2.5	9.0	2.5
3	2.5	9.0	2.5
4	2.5	9.5	2.184
5	2.5	9.5	2.184
6	2.5	9.5	2.184
7	2.5	10.0	1.921
8	2.5	10.0	1.921
9	2.5	10.5	1.700
10	2.5	11.0	1.514
11	2.5	11.0	1.514
12	2.5	11.5	1.355
13	2.5	11.5	1.355
14	2.5	11.5	1.355

$$\Sigma H_e = 26.687$$

From the equations in 5.3.2.6:

since $V_w = 55$ and $V_a = 6$ (see 5.3.2.5), $K = 6.663$.

$$\text{Whence } H_p = 6.663 \sqrt{\frac{9^5}{48^3}} = 4.869.$$

As $5H_p < \Sigma H_e < 6H_p$, five secondary rings are required.

These are located $\frac{\Sigma H_e}{6}$, $\frac{\Sigma H_e}{3}$, $\frac{\Sigma H_e}{2}$, $\frac{2\Sigma H_e}{3}$ and $\frac{5\Sigma H_e}{6}$

i.e. 4.448, 8.896, 13.344, 17.791 and 22.239 m, from the equivalent tank top.

The *first ring* is on a shell course of minimum plate thickness so no adjustment is needed.

The remaining four rings are not on courses of minimum plate thickness, hence their positions relative to the *actual* tank top must be determined.

Second ring: $8.896 - 2.5 - 2.5 - 2.5 = 1.396$ m, therefore the ring is located on the fourth course

$$1.396 \sqrt{\left(\frac{9.5}{9.0}\right)^5} + (3 \times 2.5) = 9.098 \text{ m from the tank top.}$$

Third ring: $13.344 - 2.5 - 2.5 - 2.5 - 2.184 - 2.184 = 1.476$ m, therefore the ring is located on the sixth course

$$1.476 \sqrt{\left(\frac{9.5}{9.0}\right)^5} + (5 \times 2.5) = 14.190 \text{ m from the tank top.}$$

Fourth ring: $17.791 - (3 \times 2.5) - (3 \times 2.184) - 1.921 = 1.818$ m, therefore the ring is located on the eighth course

$$1.818 \sqrt{\left(\frac{10.0}{9.0}\right)^5} - (7 \times 2.5) = 19.866 \text{ m from the tank top.}$$

In its ideal position this ring stiffener comes within 150 mm of a horizontal seam; therefore it must be moved. It is obvious in this instance to move the ring to 19.850 from the tank top. Therefore, repositioning of fourth ring on equivalent shell:

$$19.850 - (7 \times 2.5) = 1.806 \text{ m down on the eighth course.}$$

$$\sqrt{\left(\frac{10.0}{9.0}\right)^5}$$

$$\text{therefore on equivalent shell} = 17.791 - (1.818 - 1.816) = 17.779 \text{ m,}$$

$$\text{therefore remaining unstiffened equivalent shell} = 26.687 - 17.779 = 8.908 \text{ m}$$

$$\text{therefore one more ring is required at } 17.779 + 8.908/2 = 22.233 \text{ m}$$

$$\text{as } 8.908/2 = 4.454 < H_p < 8.908.$$

Fifth ring: $22.233 - (3 \times 2.5) - (3 \times 2.184) - (2 \times 1.921) - 1.7 - 1.514 = 1.125$ m therefore the ring is located on the eleventh course

$$1.125 \sqrt{\left(\frac{11}{9}\right)^5} + (10 \times 2.5) = 26.858 \text{ m from the tank top.}$$

The secondary rings are therefore 4.418, 9.098, 14.190, 19.850 and 26.850 m from the tank shell top and are 150 x 90 x 10 angle rings (figure 6).

NOTE. The fourth ring could have been positioned at 20.150 m from the tank top and the shell would still have been stable under the stated design conditions.

9.4 Shell plate arrangement

9.4.1 The tank shall be designed to have all courses truly vertical.

For butt-welded tanks the diameter on the centre line of each course shall be equal to the nominal diameter of the tank.

For lap-welded tanks the courses shall be staggered either side of the nominal diameter of the tank.

9.4.2 It is recommended that the distance between vertical joints in adjacent courses should not be less than one-third of the plate length. When this distance is less than one-third of the plate length, additional precautions may be necessary to prevent undue distortion.

9.5 Shell joints

9.5.1 As indicated by the design conditions defined in 9.2, the thickness of the outer shell will usually be governed by the vertical compressive loads from the roof and will generally be less than 15 mm.

9.5.2 Shell seams may be butt-welded or double-fillet-welded lap joints.

9.5.3 The procedure used for welding vertical and horizontal butt welds shall be that qualified (see clause 25). However, it is recognized that in practice continuous full penetration may not always be achieved. This need not be cause for rejection provided that the lack of full penetration is intermittent and longitudinal.

Discretion is recommended in rectifying lack of penetration because repair welds may not improve the integrity of the tank.

9.5.4 The procedure used for welding vertical and horizontal double fillet lap welds shall be that stated in the welding procedure specification (see clause 25). Details of the double fillet lap welds shall be as indicated in figure 7.

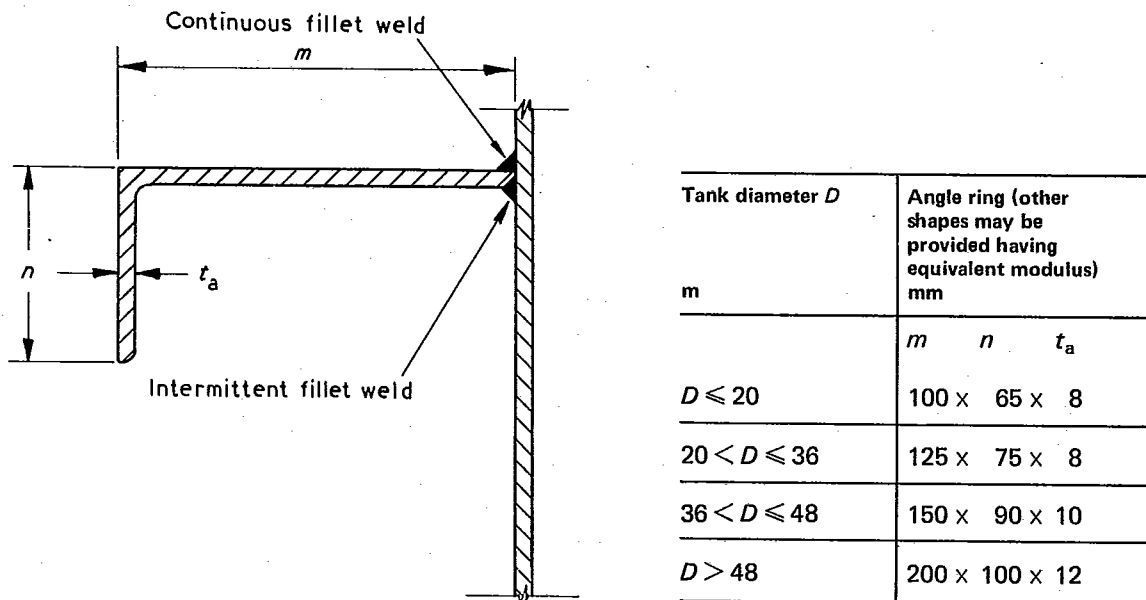


Figure 6. Shell stiffening rings (see 9.3.2)

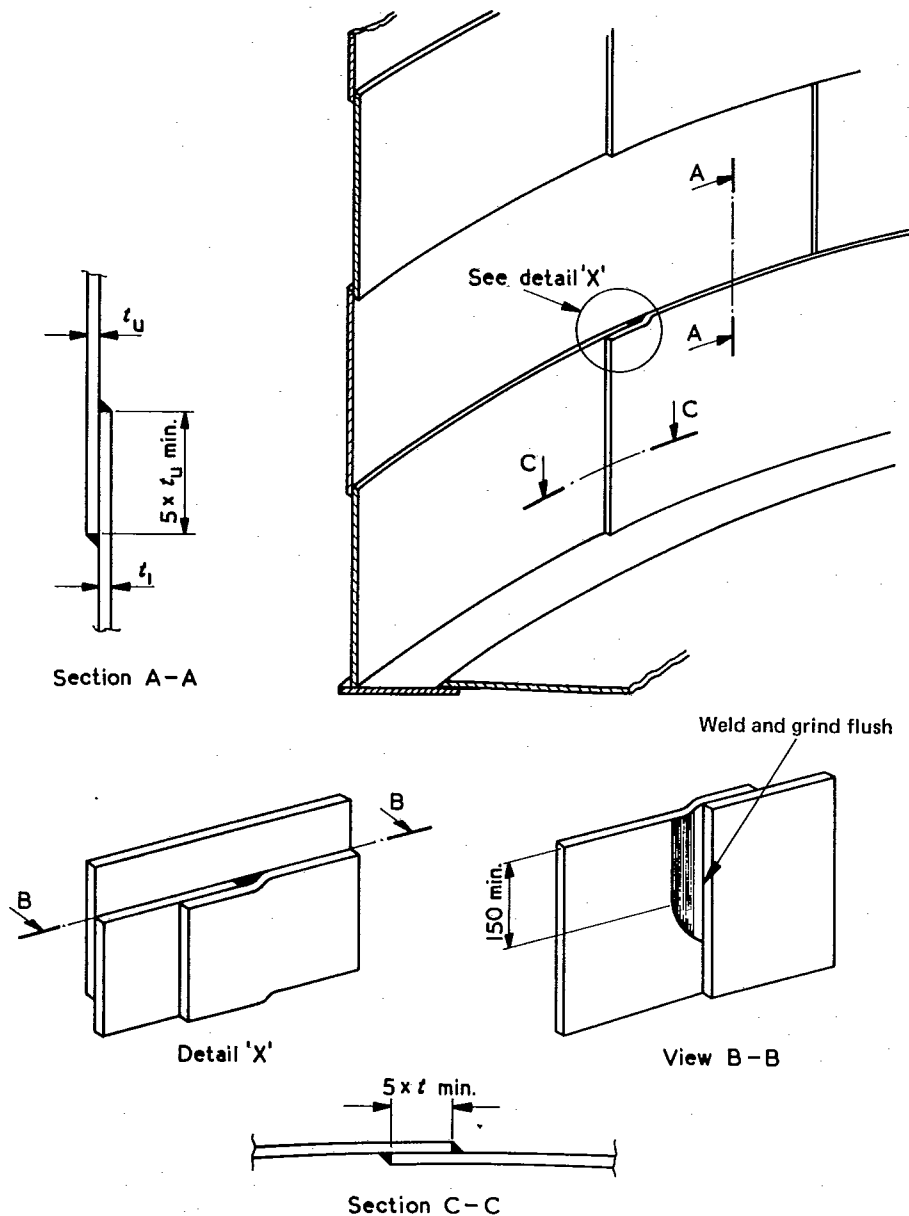


Figure 7. Typical layout of lap-welded outer tank shell

10. Outer tank roof

10.1 Roof loads. The roof shall be designed to support the loads as described in 7.4.

10.2 Type of roof

10.2.1 It is recommended that the roof shall be of the self-supporting dome or cone roof type; in the latter case the roof slope shall be 1 in 5 unless otherwise agreed between purchaser and manufacturer.

10.2.2 Where a dome roof is adopted, the radius of curvature shall be the subject of agreement between the purchaser and the manufacturer, but normally it shall be in the range of 0.8 to 1.5 times the diameter of the tank shell.

10.3 Roof plating with supporting structure

10.3.1 The minimum nominal thickness of all roof plating shall be 5 mm.

10.3.2 The steel used for construction of the roof members should have a nominal thickness of not less than 5 mm.

10.3.3 The roof-supporting structure shall be designed in accordance with BS 449. The spacing of roof purlins for cone roofs shall be such that the span between them shall not exceed 1.70 m except where one edge of the panel is supported by the top curb of the tank, when the maximum span may be increased to 2.0 m.

For coned roofs with plates of greater than minimum thickness and for domed roofs, this spacing may be increased by agreement between purchaser and manufacturer.

10.3.4 Lapped roof plates shall be continuously fillet welded on the outside with a minimum lap of 25 mm. They may be lapped so that the lower edge of the uppermost plate is beneath the upper edge of the lower plate in order to minimize the possibility of condensate moisture entering the lap joint.

10.3.5 Seams in the roof plating that is included as part of the compression area, shall be butt welded. The remaining seams in the roof plating may also be butt welded, or welded lap joints may be used.

10.3.6 The roof plate thickness shall be checked for internal pressure using equation (1) in 10.4.2. The joint efficiency shall be taken as 1.0 for butt welds and 0.35 for single-sided lap welds and 0.65 for double-sided lap welds and allowable stress as two-thirds of the yield strength.

10.3.7 Where the roof plate is not ultimately to be welded to the supporting frame, the roof framing shall be provided with bracing in the plane of the roof surface or between trusses, where these occur, to the following requirements:

(a) Cross bracing in the plane of the roof surface shall be provided in at least 2 pairs of adjacent bays on all roofs exceeding 15 m diameter. Pairs of braced bays shall be spaced evenly around the tank circumference.

(b) Additional vertical ring bracing, on trussed roofs only, shall be provided in an approximately vertical plane between the trusses to the following requirements:

- (1) $15 \text{ m} < \text{roof diameter} \leq 25 \text{ m}$: 1 ring
- (2) $\text{roof diameter} > 25 \text{ m}$: 2 rings

10.3.8 For roofs designed to be welded to the roof-supporting structure it may not be necessary to include cross bracing as specified in 10.3.7(a). Care however

must be exercised during construction before the welding is complete and temporary cross bracing may be required.

10.4 Roof plating without supporting structure (membrane roofs)

10.4.1 All membrane roofs shall be of butt-welded or double-lap-welded construction.

10.4.2 These roofs shall be designed to resist buckling due to external loading and shall be checked for internal pressure.

$$\text{For pressure } t_r = \frac{PR_1}{20 S \eta} \quad (\text{for spherical roofs}) \quad \dots (1)$$

$$= \frac{PR_1}{10 S \eta} \quad (\text{for conical roofs})$$

$$\text{for buckling } t_r = 40 R_1 \sqrt{\frac{10 P_e}{E}} \quad \dots (2)$$

where

- R_1 is the radius of curvature of roof (in m) (for conical roofs = $R/\sin\theta$; see figure 8)
- P_e is the external loading (in kN/m^2)
- E is Young's modulus (in N/mm^2)
- p is the internal pressure (in mbar)
- S is the allowable design stress (N/mm^2)
- η is the joint efficiency factor as defined in 10.3.6
- t_r is the roof plate thickness (in mm)

10.5 Compression area. This is the region at the junction of the shell and the roof that is considered to resist forces imposed by the internal pressure. The maximum widths of plates making up the compression region shall be as shown in figure 8 (shaded areas).

The area to be provided shall be not less than that determined by the following equation:

$$A = \frac{50 p R^2}{S_c \tan\theta}$$

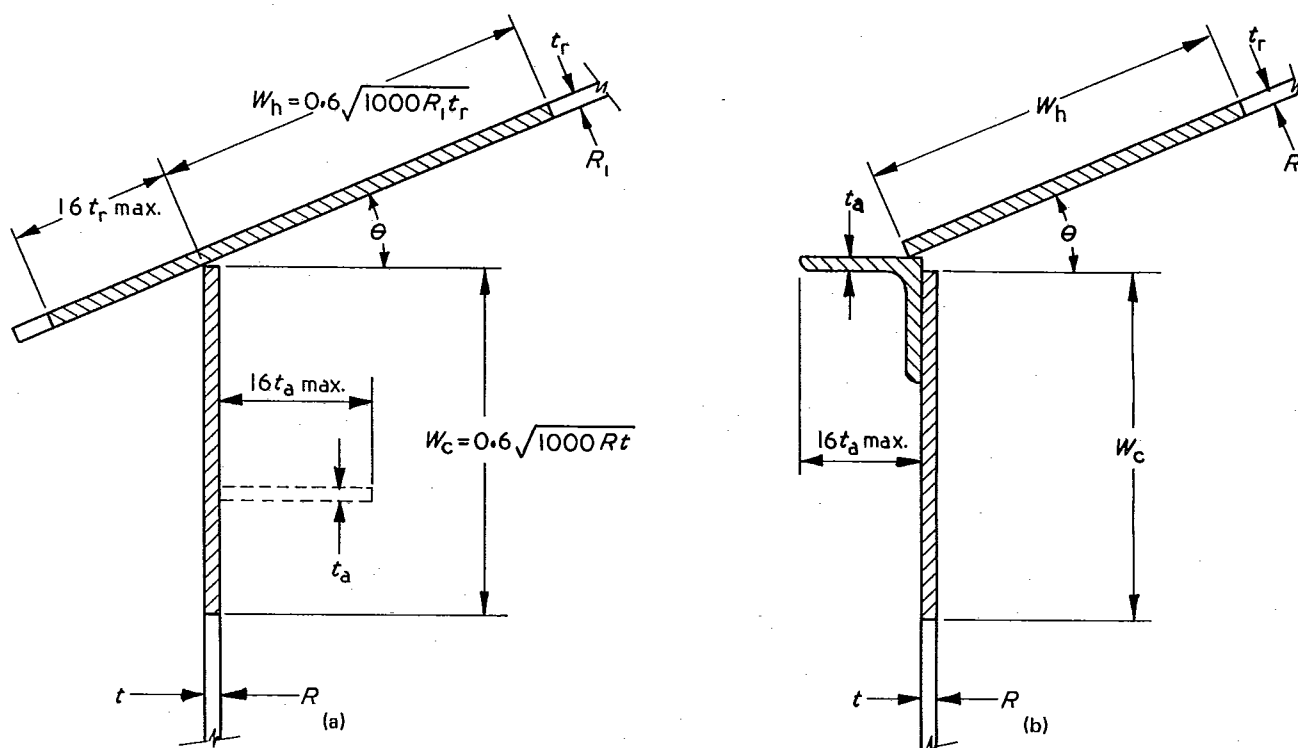
where

- A is the area required (in mm^2)
- p is the internal pressure, less weight of roof sheets (in mbar)
- θ is the slope of the roof meridian at roof-shell connection (in degrees). See figure 8
- R is the radius of the tank (in m)
- S_c is the allowable compressive strength (in N/mm^2)
Unless otherwise specified this shall be taken as 120 N/mm^2 .

If a horizontal girder is required to provide additional cross-sectional area, this girder shall be placed as close to the junction as possible and always less than W_c (see figure 8) from the junction.

The compression area shall be checked for tension loading due to external loads and/or vacuum condition.

When using a structurally supported roof, care shall be taken to avoid excessive bending in the compression region at the rafter connection to the shell periphery.



where

R_1 = radius of curvature of roof (m)
(for conical roofs = $R/\sin\theta$)

R = radius of tank shell (m)

t = thickness of shell (mm)

t_a = thickness of angle stiffener (mm)

t_r = thickness of roof plate at compression ring (mm)

Figure 8. Shell-roof compression areas (see 10.5 and 16.7)

The following minimum sizes of top curb angle shall be provided:

Tank diameter (D)	Size of curb angle
m	mm
$D \leq 10$	60 x 60 x 6
$10 < D \leq 20$	60 x 60 x 8
$20 < D \leq 36$	80 x 80 x 10
$36 < D \leq 48$	100 x 100 x 12
$D > 48$	150 x 150 x 10

11. Outer tank mountings

11.1 General. This clause covers the design of mountings attached to the outer tank.

Openings in the outer tank shell or roof normally fulfill one of the following needs:

- provide entry or exit of personnel, insulation or purge medium to or from the interspace between inner and outer tanks.
- provide entry or exit of personnel, product or vapour to or from the inside of the inner tank. Normally this also includes gauging devices that are sealed against vapour pressure.

This section covers the type (a) openings and that part of type (b) openings that is directly attached to the outer tank. Attention is drawn to clauses 17 and 18, which cover other openings.

11.2 Shell manholes and shell nozzles of outside diameter 80 mm or more

11.2.1 The thickness of the manhole and nozzle bodies shall be not less than that given in table 2.

11.2.2 The cross-sectional area of reinforcement provided, measured in the vertical plane containing the axis of the mounting, shall be not less than

$$0.75d \times t$$

where

- d is the diameter of the hole cut in the shell plate, and
 t is the design thickness of the shell plate.

The reinforcement may be provided by any one or any combination of the following three methods. A corrosion allowance on any surface shall be excluded from the computation of reinforcement required.

- The addition of a thickened shell insert plate (see figures 9 and 22) or a circular reinforcing plate, the limit of reinforcement being such that

$$1.5d \leq d_o \leq 2d$$

where d_o is the effective diameter of reinforcement. A non-circular reinforcing plate may be used provided the minimum requirements are met.

- The provision of a thickened nozzle or manhole body. The portion of the body that may be considered as reinforcement is that lying within the shell plate thickness and within a distance of four times the body thickness from the shell plate surface unless the body

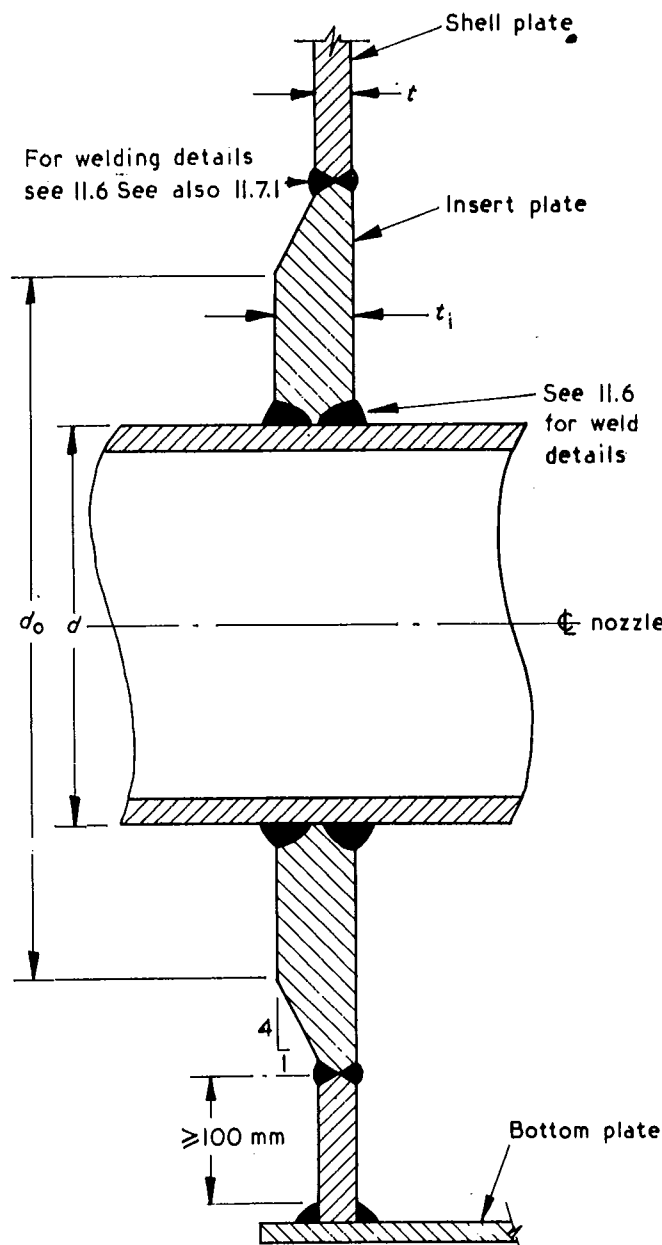


Figure 9. Shell-insert-type reinforcement (see 11.2.2 and 17.2.2)

Table 2. Manhole and nozzle body thickness

Outside diameter d_n	Manhole and nozzle body thickness t_p
mm	mm
$d_n \leq 50$	5.0
$50 < d_n \leq 75$	5.5
$75 < d_n \leq 100$	7.5
$100 < d_n \leq 150$	8.5
$150 < d_n \leq 200$	10.5
$200 < d_n$	12.5

thickness is reduced within this distance, when the limit is the point at which the reduction begins.

(c) The provision of a shell plate thicker than that required by 9.2 subject to the limits of 9.1.3. The limit of reinforcement is that specified in (a) above.

11.2.3 As an alternative to the area replacement methods given in 11.2.2, the reinforcement may be made by the provision of a thickened nozzle body protruding to both sides of the shell plate as shown in figure 10. The thickness of the nozzle shall be determined by reference to figure 11 such that the stress concentration factor j shall not exceed 2.

11.2.4 Shell manholes, where provided, should have a minimum diameter of 600 mm.

11.3 Shell nozzles of outside diameter less than 80 mm

These nozzles need no additional reinforcement provided that the thickness of the body is not less than that given in table 2. Set-on nozzles (see figure 20) may be used provided that the plates are checked close to the opening to ensure that no injurious laminations are present. For this purpose ultrasonic or magnetic crack detection is recommended.

11.4 Roof manholes and nozzles. All roof openings shall be reinforced as for shell openings in accordance with 11.2 or 11.3.

The roof manholes shall have minimum inside diameter of 500 mm. They shall be suitable for attachment by welding to the tank roof sheets.

The manhole covers shall be of the multiple-bolt fixed or hinged type as required by the purchaser.

Flanged roof nozzles shall be in accordance with figure 12.

11.5 Additional loads. Nozzles shall be designed for the loads specified in 7.3 (h).

11.6 Nozzle welding details

11.6.1 Typical weld details for nozzles, manholes and other openings are shown in figures 13 to 21. Other forms of joint preparation are permitted by agreement between the manufacturer and the purchaser. The partial penetration welds shown in figure 19 (details e and f) are permitted if the shell thickness (t) is not more than 12.5 mm and the allowable design stress (S) is less than 170 N/mm^2 .

11.6.2 The toes of fillet welds connecting a nozzle or a reinforcing plate to the shell, or the centre line of a butt weld connecting an insert plate to the shell, shall not be closer than 100 mm to the centre line of any other shell butt joint, the toe of the shell-to-bottom fillet weld, or the toe of a fillet weld connecting an adjacent attachment to the shell. The reinforcing plate or insert plate may be extended to the shell-to-bottom junction provided the plate intersects the bottom at 90° (see figure 22).

11.6.3 The leg length of the welds connecting set-through nozzles to the shell need not be larger than twice the wall thickness of the mounting. (For example, see figures 13 to 15.)

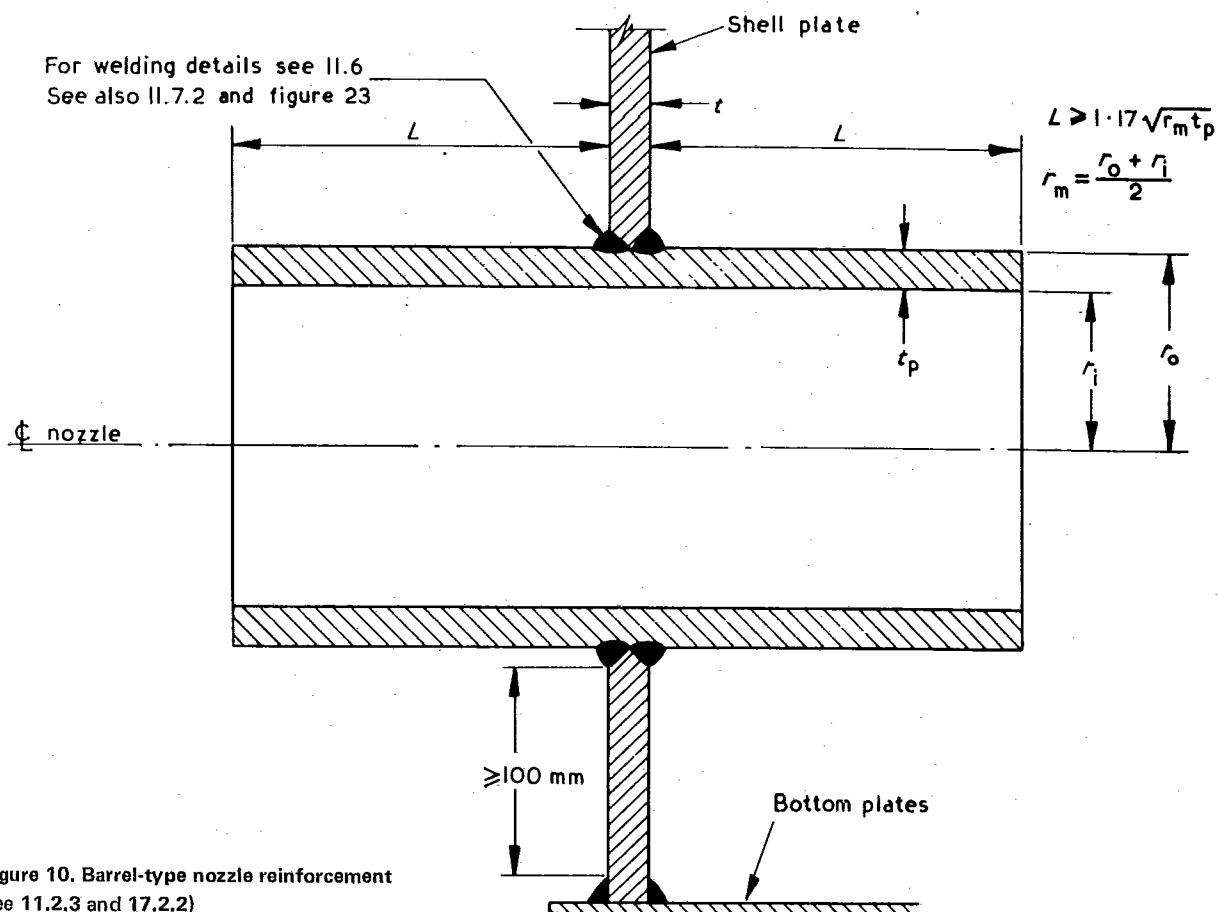


Figure 10. Barrel-type nozzle reinforcement
(see 11.2.3 and 17.2.2)

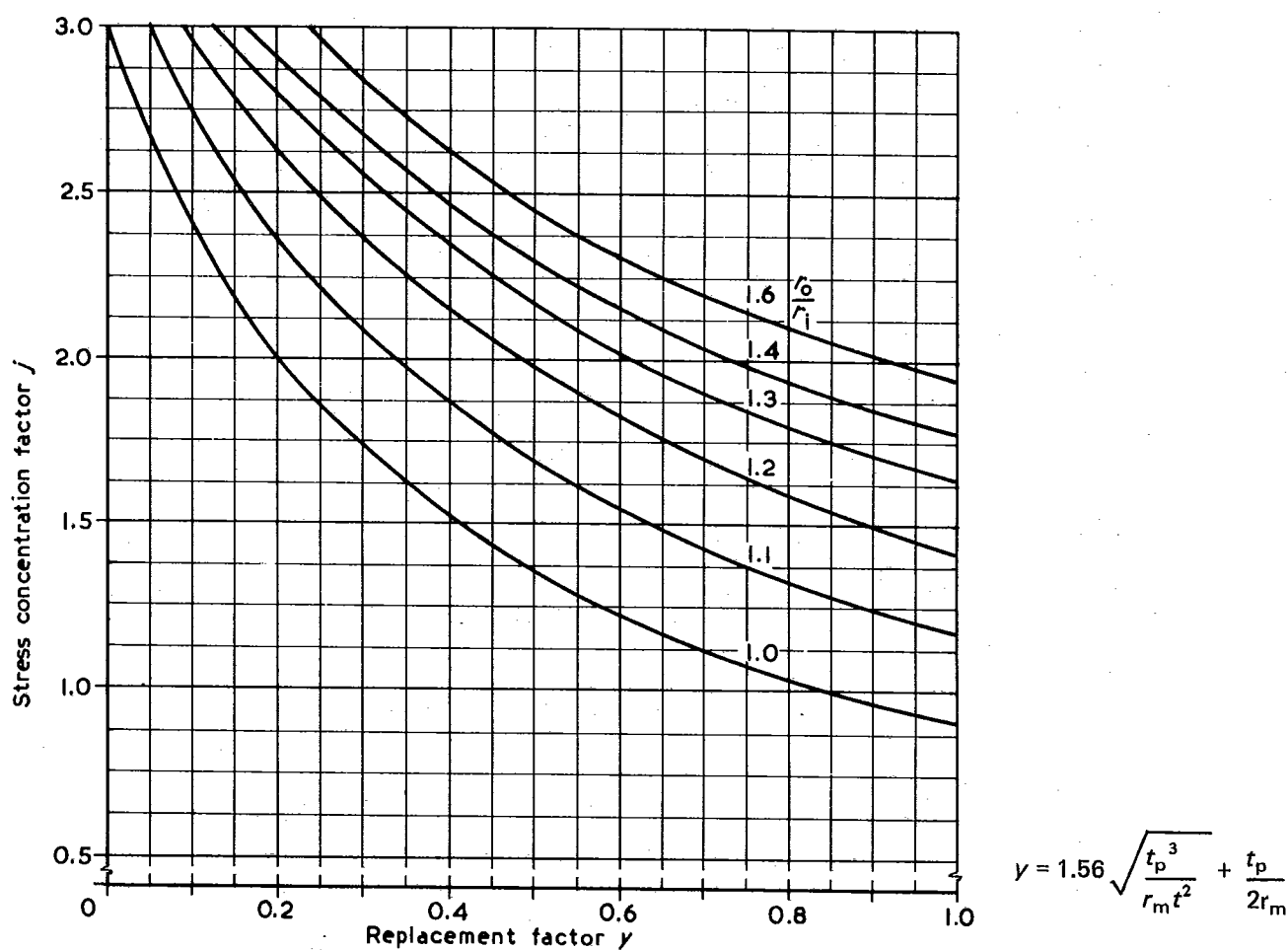
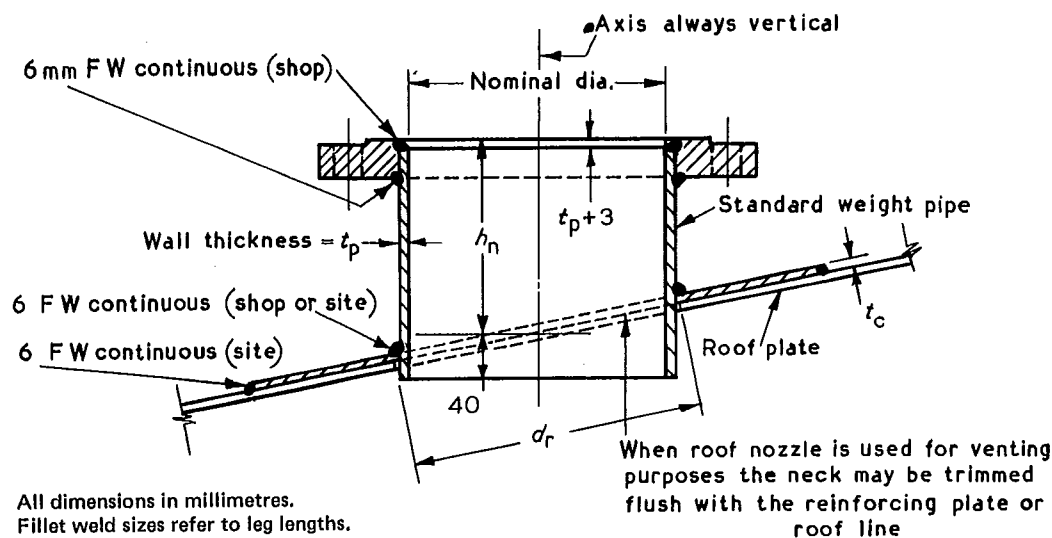
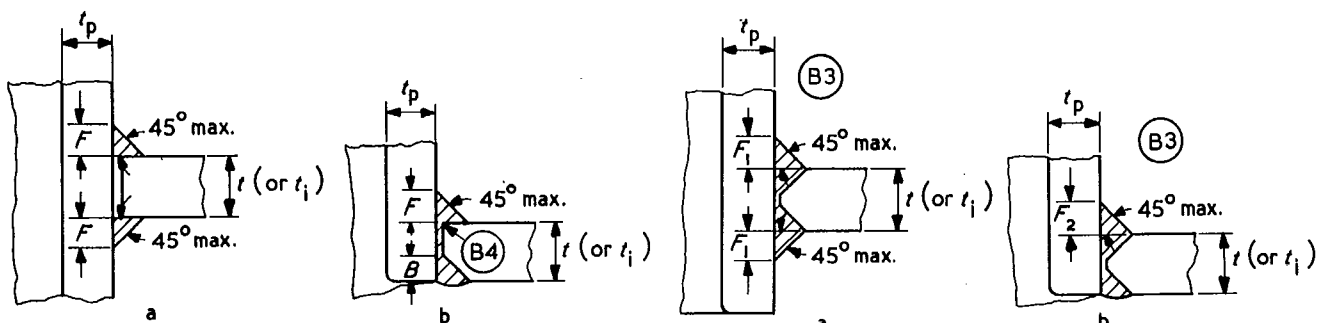


Figure 11. Graph for the determination of the thickness of barrel-type nozzle reinforcement (see 11.2.3 and 17.2.2) Rose, R. T. Reinforcement of manholes, *British Welding Journal*, October 1961



Nominal diameter of nozzle		Outside diameter of pipe	Diameter of hole in roof plate d_r	Height of nozzle h_n
in	mm	mm	mm	mm
1	25	34	36.5	150
2	50	60	63.5	150
3	80	89	92.5	150
4	100	114	117.5	150
6	150	168	171.5	150
8	200	219	225.5	150
10	250	273	279.5	200
12	300	324	330.0	200

Figure 12. Flanged roof nozzles (see 11.4 and 17.3.1)



$F = B$ = lesser of t and t_p , with a minimum of 6
 $t_p = 12.5$ maximum

NOTE 1. In cases where the shell thickness t is used to derive other dimensions, or as a recommended restriction on the use of a detail, the insert plate thickness t_i is to be substituted in the wording when insert plates are being used.

NOTE 2. Reinforcing fillets shall at least cover the penetration welds beneath.

All dimensions in millimetres.

Figure 13. Weld details for connection of mountings: set-through type (preferred details) : $t = 20$ mm (maximum) See figure 21 for standard weld details.

F_1 = lesser of $t/2$ and $t_p/2$, with a minimum of 6
 F_2 = lesser of t and t_p , with a minimum of 6
 t_p exceeds 12.5

All dimensions in millimetres.

Figure 14. Weld details for connection of mountings : set-through type (preferred details) : $t = 20$ mm (maximum) See figure 21 for standard weld details.