

SPECIFICATION FOR
VERTICAL CYLINDRICAL WELDED
STEEL STORAGE TANKS FOR
LOW-TEMPERATURE SERVICE:
SINGLE-WALL TANKS FOR
TEMPERATURES DOWN TO -50°C

BS 4741 : 1971

BRITISH STANDARDS INSTITUTION

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The Institution desires to call attention to the fact that this British Standard does not purport to include all the necessary provisions of a contract.

In order to keep abreast of progress in the industries concerned, British Standards are subject to periodical review. Suggestions for improvements will be recorded and in due course brought to the notice of the committees charged with the revision of the standards to which they refer.

A complete list of British Standards, numbering over 9000, fully indexed and with a note of the contents of each, will be found in the BSI Catalogue. The BSI Catalogue may be consulted in many public libraries and similar institutions.

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 449. The use of structural steel in building.
- BS 1501. Steels for fired and unfired pressure vessels. Plates.
- BS 1503. Steels for fired and unfired pressure vessels. Forgings.
- BS 1506. Carbon and alloy steel bars for bolting material.
- BS 1560. Steel pipe flanges and flanged fittings (nominal sizes $\frac{1}{2}$ in to 24 in) for the petroleum industry.
- BS 2600. General recommendations for the radiographic examination of fusion welded butt joints in steel.
- BS 2654. Vertical steel welded storage tanks with butt-welded shells for the petroleum industry.
- BS 3603. Steel pipes and tubes for pressure purposes. Carbon and alloy steel: low temperature duties.
- BS 3792. Recommendations for the installation of automatic liquid level and temperature measuring instruments on storage tanks.
- BS 4360. Weldable structural steels.
- BS CP3. Code of basic data for the design of buildings.

and to the following publications (obtainable through the British Standards Institution):

American Petroleum Institute Recommended Practice 2000. Guide for venting atmospheric and low-pressure storage tanks.

ISO Recommendation R 630. Structural steels.

British Standards are revised, when necessary, by the issue either of amendment slips or of revised editions. It is important that users of British Standards should ascertain that they are in possession of the latest amendments or editions.

The following BSI references relate to the work on this standard :
Committee reference PEE/12

Draft for comment 69/21595

CO-OPERATING ORGANIZATIONS

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

- | | |
|--|--------------------------------------|
| British Mechanical Engineering Confederation | Department of Trade and Industry |
| British Rubber Manufacturers' Association | *Gas Council |
| *British Steel Industry | *Oil Companies Materials Association |
| *Council of British Manufacturers of Petroleum Equipment | |

The 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 standard:

- | | |
|---|---------------------------------------|
| Aluminium Federation | Institution of Chemical Engineers |
| British Chemical Plant Manufacturers' Association | Institution of Gas Engineers |
| Chemical Industries Association | Tank and Industrial Plant Association |
| Engineering Equipment Users' Association | Welding Institute |

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BRITISH STANDARD SPECIFICATION FOR VERTICAL CYLINDRICAL WELDED STEEL STORAGE TANKS FOR LOW TEMPERATURE SERVICE: SINGLE WALL TANKS FOR TEMPERATURES DOWN TO -50°C

FOREWORD

This British Standard, prepared under the authority of the Petroleum Equipment Industry Standards Committee, is designed to provide industry with tanks of adequate safety and reasonable economy for the storage of refrigerated products.

The requirements for material selection in this standard have been based on the results of a number of notched and welded Wells Wide Plate Tests (WWP tests) on carbon and carbon/manganese steel plates, carried out at the Welding Institute (previously British Welding Research Association). In particular, the proposals are related to the results reported in 'Mild Steel for Pressure Equipment Sub-zero Temperatures', British Welding Journal, March 1964, but all other known WWP test data has been taken into account. They also reflect many subjective assessments of practice to date in this field as permitted by current British, American and German codes.

Wells Wide Plate Test data all indicate that resistance to brittle fracture is dependant upon:

- (1) Notch toughness of the material.
- (2) Plate thickness.
- (3) Extent of crack-like defects present; (it is believed that if such defects are absent, brittle fracture will not be a problem at normal rates of loading).
- (4) Degree of local embrittlement at tip of pre-existing defects; (in the case of carbon and carbon/manganese steels, post-weld heat treatment in the stress relieving range temperature is effective in removing severe embrittlement arising as a result of welding and/or flame cutting operations).

SPECIFICATION

1. GENERAL

1.1 Scope. This British Standard relates to the materials, design, fabrication, erection and testing of single wall, flat-bottom, vertical, cylindrical welded steel storage tanks for above ground storage of products with a specific gravity ≤ 0.8 and at a service temperature down to -50°C . This standard is not applicable to the storage of products with a specific gravity > 0.8 ; in this case special agreement will be required between the purchaser and the manufacturer.

1.2 Design conditions. Tanks shall be designed to suit the pressure and vacuum which will be required for service but shall not exceed 140 mbar* gauge internal vapour pressure and 6 mbar gauge internal vacuum.

The minimum design metal temperature shall be -50°C .

1.3 Information to be supplied by the purchaser. The following information shall be supplied by the purchaser in his enquiry:

* The millibar and the bar are used in certain clauses in this standard to express values of pressure.

1 mbar = 10^3 N/m^2
1 bar = 10^5 N/m^2

(1) Geographical location of the tank and wind speed as specified in 3.1.7.

(2) Diameter and height or the capacity of the tank, including ullage. Where only capacity of the tank is specified, maximum boil-off and ground conditions shall also be specified.

(3) All relevant properties of the contained fluid, including the specific gravity and corrosion allowance (if required.)

(4) The design vapour pressure and vacuum conditions inside the tank.

(5) The minimum and maximum design temperatures.

(6) The size, number and type of all mountings required, showing locations.

(7) Details of flange drilling if not in accordance with BS 1560†.

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

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(8) Details of painting requirements and whether pickling, grit or shot blasting is required.

(9) The lines of demarcation of responsibility between the designer, manufacturer and erector of the tank, when these are not the same.

(10) Method of despatching tank plates for export.

(11) Whether welding electrodes and/or key plating equipment are to be supplied by the tank manufacturer.

(12) Other standards or specifications which are to be read in conjunction with this standard.

1.4 The attention of purchasers is drawn to the desirability of considering tank and foundation designs together, to give the most economical arrangement (see Appendix A). The design basis of foundations shall be agreed between the purchaser's Civil Engineer and the tank designer at the time of ordering.

2. MATERIALS

2.1 Specifications. 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 the purchaser and the manufacturer, provided such materials meet the requirements of 2.2, 2.3 and 2.4.

Steels having a minimum specified yield point in excess of 385 N/mm² shall not be used.

Plates: BS 1501*, BS 4360†, ISO/R 630‡, subject to the requirements of 2.4 and 2.5.

Sections, bars: BS 4360†, ISO/R 630‡.

Forgings: BS 1503§ (Carbon and carbon manganese steels only).

Bolting material: BS 1506||.

Piping: BS 3603¶.

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

2.3 Chemical composition. For plates thicker than 20 mm and up to and including 25 mm the carbon equivalent shall not exceed 0.43 %. For plates thicker than 25 mm the carbon equivalent shall not exceed 0.42 %. The carbon equivalent shall be calculated from the ladle analysis using the formula:

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

By agreement between the purchaser and the manufacturer a check analysis may be required, in which case:

$$C + \frac{Mn}{6} \text{ shall not exceed } 0.43 \%$$

For steels stronger than Grade 28, the phosphorus plus the sulphur shall not exceed 0.08 %.

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

† BS 4360, 'Weldable structural steels'.

‡ ISO/R 630, 'Structural steels'.

§ BS 1503, 'Steels for fired and unfired pressure vessels. Forgings'.

|| BS 1506, 'Carbon and alloy steel bars for bolting material'.

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

The nitrogen content shall not exceed 0.01 % except that, for non-ageing steels, the maximum nitrogen content may, by agreement between purchaser and manufacturer, be increased to 0.02 %.

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2.4 Notch ductility.

The selection of materials for all forgings, bottom, shell and roof plates and structural sections shall be as given in 2.4.1 and 2.4.2.

2.4.1 Charpy-V impact tests shall be performed and the absorbed energy shall be at least equal to the values shown in Table 1, which are the average of three test specimens, and the temperature shall be as given in Table 2.

No individual value shall be less than 75 % of the average values given in Table 1.

All materials shall be impact tested.

TABLE 1. CHARPY-V IMPACT TESTS (AVERAGE OF THREE TEST SPECIMENS)

Specimen size	Impact test values		
	Tensile strength $\leq 450 \text{ N/mm}^2$	Tensile strength $> 450 \text{ N/mm}^2$	Weld metal (see 14.3.5.3)
10 mm x 10 mm	27 J	41 J	27 J
10 mm x 7.5 mm	22 J	33 J	22 J
10 mm x 5 mm	19 J	29 J	19 J
10 mm x 2.5 mm*	10 J	15 J	—

TABLE 2. CHARPY-V TEST TEMPERATURES

Material thickness t (mm)	Minimum design metal temperature		
	Not colder than -10°C	Not colder than -35°C	Not colder than -50°C
$t \leq 20$	-10°C	-35°C	-50°C
$20 < t \leq 30$	-20°C	-45°C	-60°C
$30 < t \leq 40$	-30°C	-55°C	—

2.4.2 The reference thickness for determining the notch ductility requirement for sections shall be the nominal thickness of the flange or web, whichever is the greater.

NOTE. For compression rings having thicknesses up to 40 mm the impact values need not exceed those required for 20 mm thick plate given in Tables 1 and 2.

*For materials 5 mm thick or less, the impact test specimen shall be 10 mm x 2.5 mm, unless otherwise agreed by the purchaser and the manufacturer at the time of order. Specimens less than 10 mm x 5 mm in size shall not be used for qualifying a welding procedure.

2

2

2

2.5 Structural steel. Structural steel, which is impact tested at a rate of not less than 40 tonnes per cast, may be used for all parts of the tank other than the shell and the bottom plates attached to the shell. Structural steel may be used for the shell and bottom plates connected to the shell, provided that either the steel is impact tested per rolled plate or the Charpy-V impact test temperature is 15 °C lower than that indicated in Table 2.

2.6 Mountings

2.6.1 Reinforcing plates shall be of the same nominal strength as the plates to which they are attached. Nozzle bodies and insert plates shall also meet these requirements, unless otherwise agreed between the purchaser and the manufacturer.

2.6.2 Permanent attachments, reinforcing plates, insert plates, nozzle bodies and flanges shall meet the notch ductility requirements of 2.4.

For welding neck flanges the reference thickness shall be taken as the thickness at the weld or 25 % of the flange thickness, whichever is the greater. For hubbed or slip-on flanges the reference thickness shall be taken as the thickness of the branch to which the flange is welded or 25 % of the flange thickness, whichever is the greater.

2.7 Information to be provided by the steelmaker. The steelmaker shall state at the time of the order the condition of supply of all plates (e.g. as rolled, normalized) and the nominal composition of the steel. The ladle analysis and check analyses when required, shall be reported as required by the steel specification together with values for all elements specified in 2.3 and including any deliberate additions (e.g. aluminium, niobium, boron, vanadium, etc.).

2.8 Information to be provided by the steel purchaser. The purchaser of the steel shall specify in his order to the steelmaker that the plates are to meet the requirements of this British Standard.

3. LOADINGS

3.1 Design loads. The tank shall be designed for the most severe possible combination of the following loadings:

3.1.1 Dead loads

3.1.2 Superimposed loads. The roof and supporting structures shall be designed to support a minimum superimposed load of 1.2 kN/m² of projected area. This superimposed load is the sum of either internal vacuum (6 mbar) and snow load, or internal vacuum (6 mbar) and live load.

3.1.3 Contents. The weight of the product from empty to full, with or without the specified vapour pressure. (The maximum design vapour pressure is 140 mbar)

3.1.4 The hydrostatic test load

3.1.5 Loads resulting from connected piping. The purchaser shall state the magnitude and direction of any external loads which might be applied to the shell or shell connections.

The design for such loadings shall be a matter for agreement between the purchaser and the manufacturer.

3.1.6 Insulation. By agreement between purchaser and manufacturer the weight of the insulation may be included in the minimum superimposed loadings specified in 3.1.2.

3.1.7 Wind loading. The wind speed used in the calculations shall be the maximum 3 second gust speed estimated to be exceeded on 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.

3.1.8 Seismic loads, if applicable (see Appendix A).

4. BOTTOM DESIGN

4.1 General

4.1.1 All tank bottoms shall have a ring of annular plates under the shell of minimum width 500 mm. The joints between these plates shall be butt welded as indicated in Fig. 1, section B-B. Other bottom plates may also be butt-welded or welded lap joints may be used.

4.1.2 The minimum thickness of all bottom plates shall be 6 mm. The minimum thickness of the annular plate shall be in accordance with the following:

8 mm when the bottom course of shell plating is 19 mm thick or less.

10 mm when the bottom course of shell plating is over 19 mm up to and including 32 mm thick.

11 mm when the bottom course of shell plating is over 32 mm thick.

4.1.3 The annular plate shall be of the same material specification and grade as the bottom course of the shell plate with impact requirements relevant to the thickness of the annular plate.

* CP 3, 'Code of basic data for the design of buildings', Chapter V 'Loading', Part 2, 'Windloads'.

1

4.2 Design

4.2.1 Lap joints shall have minimum overlap of five times the thickness of the plate and shall be welded on the top side. The fillet weld shall consist of at least two passes. At the ends of cross joints in lapped plates where three thicknesses occur, the upper plate shall be hammered down and welded as indicated in details A and B of Fig. 2.

4.2.2 The radial seams connecting the ends of annular segmental plates and the joints in butt-welded bottoms shall be butt-welded with a backing strip the minimum thickness of which shall be 4.5 mm. Plates of thickness 8 mm and over shall be single-V chamfered (see Fig. 1).

4.2.3 The attachment between the bottom edge of the lowest course of shell plates and the annular plates shall be fillet welded continuously on both sides of the shell plate, and each fillet weld shall consist of at least two passes.

The leg length of both fillet welds shall be equal to the thickness of the annular plate, except that it shall not exceed that given in the following table when the shell plate thickness is less than the bottom plate thickness:

Shell plate thickness mm	Leg length of fillet weld mm
5	6
6 and over	8

5. SHELL DESIGN

5.1 Design stresses

5.1.1 The maximum allowable stress in any plate under test shall be limited to 0.85 of the minimum specified yield strength (see 2.1).

The maximum allowable design stress in any plate in service shall be the lesser of 260 N/mm² or $\frac{2}{3}$ of the minimum yield strength of the shell plate material (N/mm²).

5.1.2 In calculating the thickness of plate required, the joint efficiency factor η shall be taken as 1.00 provided that with regard to the qualifications of procedures and operators (see Section 14) and the site inspection of shell joints no relaxation is permitted of the requirements of this standard.

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

Nominal tank diameter (m)	Nominal shell thickness (mm)
Smaller than 25	6
25 to 40 inclusive	8
Over 40	10

Minimum thickness requirements 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 5.3.

The maximum thickness of shell plates shall be 40 mm.

5.2 Internal loading

5.2.1 The forces in the tank shell shall be computed on the assumption that the tank is filled to the top of the shell with the contained fluid.

However, attention is drawn to the fact that, in order to meet the requirements of other parts of this standard, the maximum product filling height might be less than the

height of the shell and less than the height to which the tank has been filled during the hydrostatic test. This is based on the assumption that the density of the test liquid is less than the density of the product, i.e. chlorine storage. The design shall ensure that under no normal or emergency operating conditions can the tank be filled with product above the maximum product filling height upon which the design is based.

5.2.2 The following equations shall be used in calculating the thickness of the shell plates:

$$t = \frac{D}{20S} [98W(H - 0.3) + p] + C \quad \text{Equation (1)}$$

or

$$t = \frac{D}{20S_t} [98W_t(H - 0.3) + 1.25p] \quad \text{Equation (2)}$$

The value of t to be taken shall be the greater of those computed by Equations (1) and (2). In Equations (1) and (2)

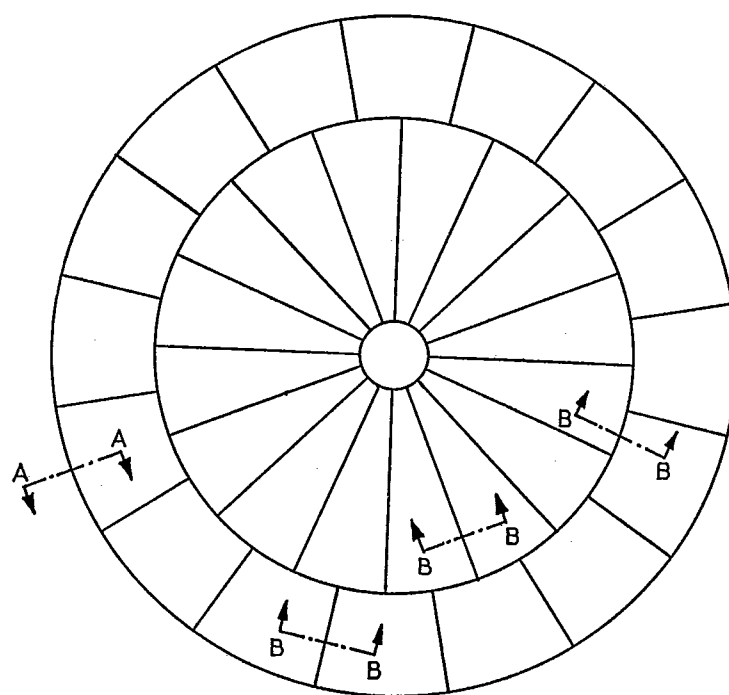
t = calculated minimum thickness	mm
H = height from bottom of course under consideration to the top of shell or to the maximum design product level	m
D = tank diameter	m
W = maximum density of contained liquid under storage conditions	g/ml
W_t = density of test liquid but shall not be less than 1.0	g/ml
S = allowable design stress (see 5.1.1)	N/mm ²
S_t = allowable stress under test (see 5.1.1)	N/mm ²
p = design pressure	mbar
C = corrosion allowance	mm

5.2.3 The tension force in each course shall be computed at 0.3 m above the centre line of the horizontal joint in question except when adjacent upper (U) and lower (L) courses are made from materials with different mechanical properties and $\frac{H_u - 0.3}{S_u}$ is greater or equal to $\frac{H_L - 0.3}{S_L}$.

In this case the thickness of the upper course shall be calculated using the modified formula

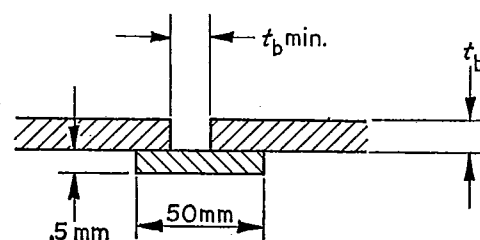
$$t = \frac{D}{20S} (98wH + p) + c. \quad \text{Furthermore, no course}$$

shall be constructed at a thickness less than that of the course above, irrespective of the materials of construction.

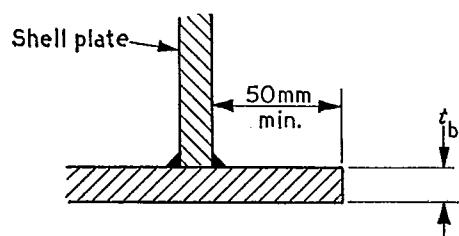


Typical radial bottom layout

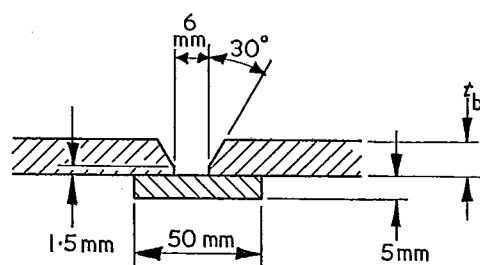
Layout of bottom with rectangular plates to be similar to Fig. 2.



Section B-B
For $t_b < 8$ mm only



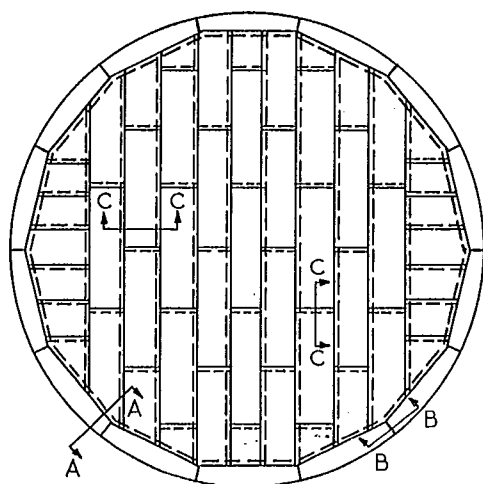
Section A-A
Fillet weld size (see 4.2.3)



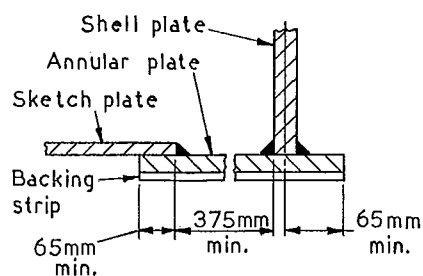
Section B-B
For values of $t_b \geq 8$ mm

Fig. 1. Butt jointed bottoms

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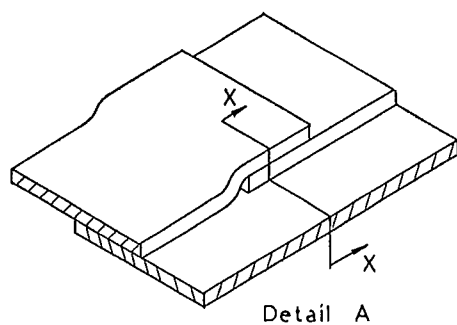


Typical bottom layout

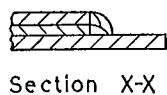


Fillet weld size, see Clause 4.2.3.

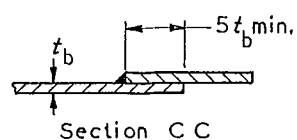
Annular plates 8mm min. thickness.
Rectangular and sketch plates
min. thickness 6mm



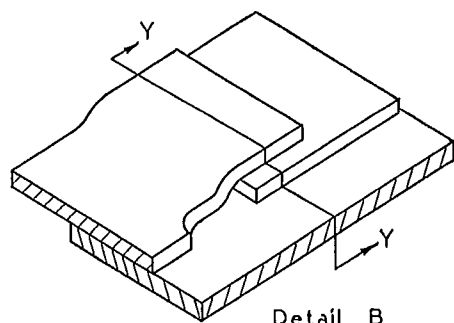
Detail A



Section X-X



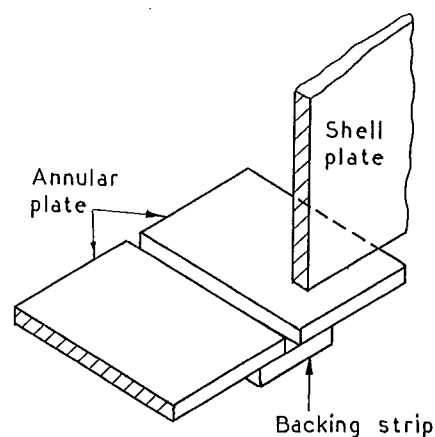
Section C C



Detail B



Section Y-Y



For details of butt weld see Sections B-B
of Fig. 1.

Annular plate joint under shell plates

Cross joints in bottom plates where three thicknesses occur

Fig. 2. Lap jointed bottoms

5.2.4. The ordered thickness shall be such that no plate is allowed to underrun the calculated minimum thickness (t) by more than 0.25 mm.

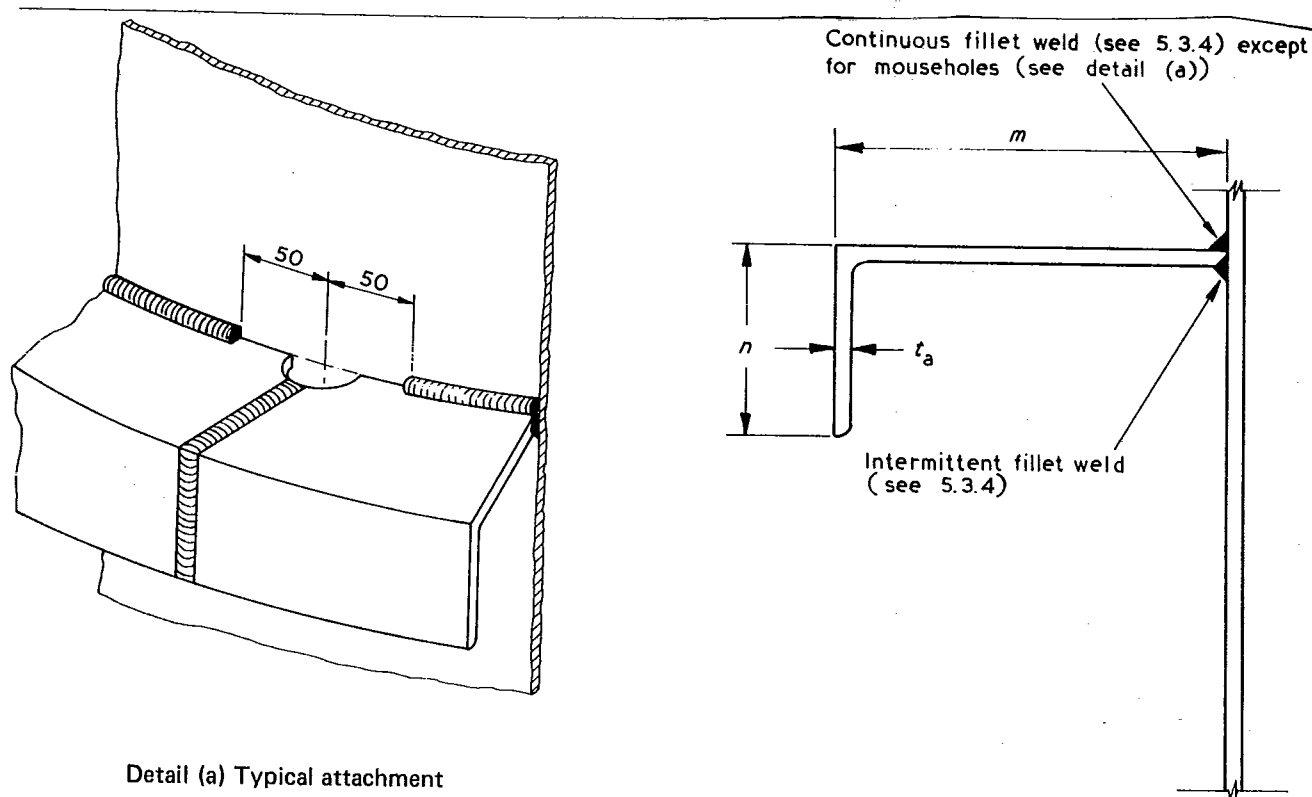
5.3 Wind and vacuum loading

5.3.1 Tank shells designed in accordance with the rules set out in this standard may require stiffening rings to

maintain roundness over the full height of the tank shell under wind and for vacuum conditions of loading.

5.3.2 The stiffening rings are not required to carry panel loading but are necessary to prevent preferential local buckling of the tank shell. The size of stiffening rings has not been related to the design loads but shall be determined with respect to tank diameter in accordance with the table given in Fig. 3. The orientation and fixing of such stiffening rings shall also be in accordance with Fig. 3.

5.3.3 The vertical positioning of stiffening rings shall be calculated by first determining 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



Tank diameter D (m)	Angle ring (other shapes may be provided having equivalent modulus) (mm)		
	m	n	t_a
$D \leq 20$	100	65	8
$D > 20$ ≤ 36	125	75	8
$D > 36$ ≤ 48	150	90	10
$D > 48$	200	100	12

Fig. 3. Shell stiffening rings (see 5.3)

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 which follows in 5.3.8. A stiffening ring shall not be located within 150 mm of a main circumferential tank seam.

5.3.4 Stiffening ring attachment

5.3.4.1 Where adjacent sections of shell stiffening rings are joined together, the fillet welds joining the ring to the shell shall be discontinued local to each junction by terminating the fillet welding approximately 50 mm either side (see Fig. 3). All craters in fillet welds shall be filled by back welding.

5.3.4.2 Junctions between adjacent sections of stiffening ring shall develop the full strength of the angle at the point of junction. Butt welds, if used, shall be designed to give complete penetration.

5.3.4.3 Whether the joint between adjacent sections is a butt weld or not, the welding of such a junction shall be such that it produces fusion between adjacent sections only, and not fusion to the shell plate surface. Positive means to prevent such fusion is required, e.g. use of a mousehole (about 20 mm radius). For a typical detail see Fig. 3.

5.3.5, The wind speed used in calculation shall be that defined in 3.1.7.

5.3.6 The design vacuum for stability calculation shall be 8.5 mbar, i.e. 6 mbar setting plus 2.5 mbar to allow accumulation for the vacuum valves to develop full design throughput. A different level of total vacuum may be used in the computation if this can be proven as justifiable.

5.3.7. Where tanks are designed to contain corrosive products or for any other reason a corrosion allowance is required, the amount of this allowance shall be specified by the purchaser and all calculations to determine shell stiffening requirements under the action of wind and/or internal vacuum conditions shall exclude this corrosion allowance.

5.3.8 Formulae

D = tank diameter m

$t_{\min}$ = thickness of top course mm

t = thickness of each course in turn mm

h = height of each course in turn below any primary ring m

H_e = the equivalent stable height of each course m

H_E = the equivalent stable full shell height at $t_{\min}$ m

V_w = design wind speed km/h

V_a = design vacuum mbar

H_P = the maximum permitted spacing of rings on shells of minimum thickness m

$$H_e = h \left(\frac{t_{\min}}{t} \right)^{5/2}$$

$$H_E = \Sigma H_e$$

$$K = \frac{95\,000}{0.275 V_w^2 + 580 V_a}$$

$$H_P = \frac{K t_{\min}^{5/2}}{D^{3/2}}$$

5.3.9 Example. A tank 335 m diameter 20 m high having eight 2.5 m courses of thickness 6.0, 6.0; 7.0, 9.0, 11.5, 13.5, 16.0, 18.0, is to be designed for a wind speed of 110 km/h. How many and what is the location and size of stiffening rings?

Course	h	t	H_e
1	2.5	6.0	2.500
2	2.5	6.0	2.500
3	2.5	7.0	1.700
4	2.5	9.0	0.910
5	2.5	11.5	0.565
6	2.5	13.5	0.330
7	2.5	16.0	0.215
8	2.5	18.0	0.163

$$\frac{8.883}{1} = H_E$$

$$V_w = 110 \quad V_a = 8.5, \quad K = 11.50 \quad H_P = 5.33$$

$H_P < H_E < 2H_P$, hence one stiffening ring is required.

This ring is 4.442 m (i.e. $H_E/2$) from the tank top on the second course of minimum thickness and more than 150 mm from a circumferential seam. The size of the ring is a 125 × 75 × 8 mm angle.

5.4 Shell plate arrangement

5.4.1 The tank shall be designed to have all courses truly vertical and the diameter on the centre line of each course shall be equal to the nominal diameter of the tank.

5.4.2 It is recommended that the distance between vertical joints in adjacent courses should be not 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.

5.5 Shell joints

5.5.1 All seams shall be butt-joints and shall have full penetration and complete fusion.

5.5.2 All horizontal seams for a distance of 150 mm at either side of each vertical seam (T-junctions), shall have full penetration and complete fusion.

The procedure used for welding portions of the girth seams between the T-junctions, shall be that qualified (see Clause 14). However, it is recognized that, in practice, continuous full penetration may not always be achieved between T-junctions. This need not necessarily be cause for rejection, provided that the lack of full penetration is intermittent, longitudinal in nature, and does not exceed approximately 10 % of the thickness of the thicker plate joined.

Some discretion is recommended against rigorous rectification of lack of penetration, since repair welds may introduce possible hazards greater than the original defect.

6. ROOF DESIGN

6.1 Loads. The roof shall be designed to support the loads as described in Section 3.

6.2 Type of roof

6.2.1 All roofs shall be of the self supporting type where the entire load is supported by the tank periphery.

6.2.2 Although cone roofs are permitted, dome roofs are recommended.

6.2.3 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.

6.3 Roof plating with supporting structure

6.3.1 The roof sheets and supporting structure shall be designed in accordance with BS 449*, for the loads specified in Clause 3.

6.3.2 Roof plating shall not be attached to the roof supporting structure.

6.3.3 The minimum thickness of all roof plating shall be 5 mm exclusive of corrosion allowance.

6.3.4 Seams in roof plating which 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.

6.3.5 The plate thickness shall be checked for internal pressure using equation (1) in 6.4.2. 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 the allowable stress of two-thirds of the yield strength.

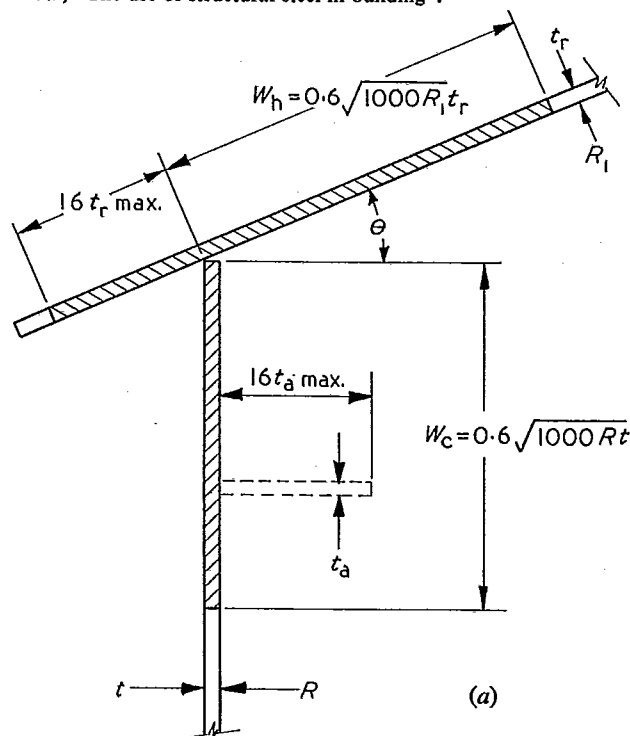
6.4 Roof plating without supporting structure (membrane roofs)

6.4.1 All membrane roofs shall be of butt-welded or double-lap-welded construction and shall be designed for the loads specified in Clause 3.

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

$$\text{For pressure } t_r = \frac{p R_1}{20 S \eta} \quad (1)$$

BS 449, 'The use of structural steel in building'.



where R_1 = Radius of curvature of roof (m)
 R = Radius of tank shell (m)
 t = Thickness of shell (mm)
 t_r = Thickness of roof plate at compression ring (mm)

Fig. 4. Shell/roof compression areas (see 6.5)

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

where R_1 = radius of curvature of roof m

P_e = external loading kN/m²

E = Young's modulus N/mm²

p = internal pressure mbar

S = allowable design stress N/mm²

η = joint efficiency factors as defined in 6.3.5

t_r = roof plate thickness mm

6.5 Compression area. This is the region at the junction of the shell and the roof which 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 Fig. 4 (a) and (b).

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 = area required

mm²

p = internal pressure

mbar

θ = slope of meridian at roof-shell

connection (see Figs. 4(a) and (b))

degrees
m

R = radius of tank

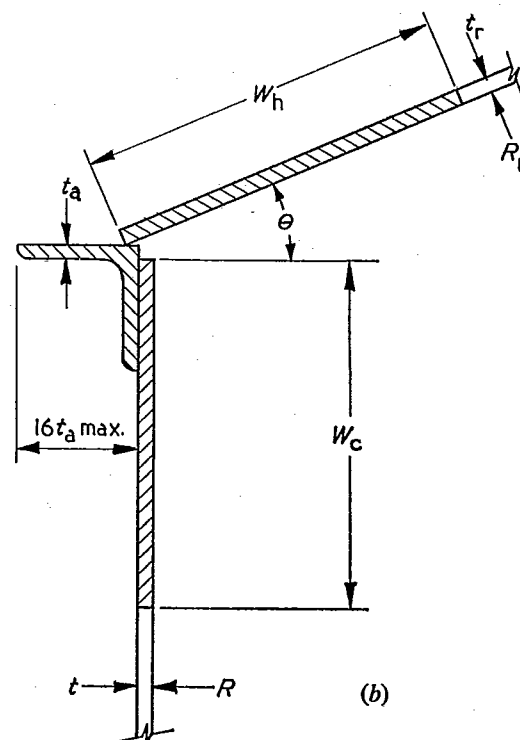
S_c = allowable compressive stress (which

unless otherwise specified shall

be taken as 120 N/mm²)

N/mm²

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 the distance of any part of its cross-section from the junction shall not exceed W_c (see Fig. 4).



The compression area shall be checked for tension loading due to external pressure 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.

7. TANK ANCHORAGE

7.1 Design. Tank anchorage shall be provided if under the worst conditions of operation there may be a tendency for the shell and the bottom plate close to the shell to lift off its foundation.

7.1.1 The design uplift on the anchorage shall take into account the following conditions:

- (1) Design roof vapour pressure.
- (2) Wind uplift pressure.
- (3) Wind overturning pressure.
- (4) Seismic force, not in combination with (2) and (3).
- (5) Weight of uninsulated shell, roof and associated structure.
- (6) Weight of shell and roof insulation.
- (7) Test roof vapour pressure.

7.1.2 The wind pressures on the tank roof and shell shall be calculated in accordance with CP 3, Chapter V, Part 2*.

7.1.3 The anchorage shall be attached to the shell in preference to the annular bottom plate. The design shall accommodate movements of the tank due to thermal changes and reduce any induced bending stresses in the shell to a minimum. A typical example is shown in Fig. 7, but other designs are permissible.

7.1.4 The design temperature for anchorage and anchorage attachments shall be the design metal temperature of the tank unless it can be shown that a higher temperature will in practice be obtained. If so, this higher temperature may be used by agreement between the purchaser and the designer. Heat transfer from the warmer parts of the structure shall be such that unacceptable characteristics do not develop which may lead to failure of the anchorage, excessive ice formation or water condensation.

7.1.5 Under the design conditions listed in 7.1.1 but excluding test conditions, the anchorage design stress shall not exceed $\frac{2}{3}$ of the yield strength.

7.1.6 If corrosion is anticipated a minimum corrosion allowance of 1 mm shall be added.

7.2 Construction

7.2.1 Anchorage spacing. It is recommended that anchorage points should be spaced at a minimum of 1 m and at a maximum of 3 m and should as far as possible be spaced evenly around the diameter.

7.2.2 Any anchor bar, bolt or strap should have a minimum cross-sectional area of 500 mm².

* CP 3, 'Code of basic data for the design of buildings', Chapter V, 'Loading', Part 2, 'Windloads'.

7.3 Testing. The anchorage shall be capable of resisting an uplift test pressure equal to 1.25 times the design anchorage uplift force. For this condition the stress in the anchorage shall not exceed 0.85 times the minimum yield strength of the anchorage material, taking into account any initial tension in the anchorage members resulting from bolting loads or loads due to transient or long term thermal movements. It is recommended that no initial tension be applied to the anchorage so that it is only loaded should an uplift force develop in the shell of the tank. Steps shall be taken before the tank goes into service to ensure that anchorage bolts cannot work loose or become ineffective over a long period.

8. MOUNTINGS

8.1 Shell manholes and shell nozzles 80 mm outside diameter and above. The minimum reinforcement requirements shall be determined by one of the following methods:

where d_o = outside diameter of reinforcement
 d = diameter of the hole cut in shell plate
 t = thickness of shell plate
 t_c = thickness of reinforcing plate
 t_i = thickness of insert plate

8.1.1 The addition of a circular reinforcing plate such that $(d_o - d) \times t_c \geq 0.75d \times t$ when $1.5d \leq d_o \leq 2d$

8.1.2 The provision of a thickened shell insert plate (see Fig. 8) such that

$$(d_o - d) \times (t_i - t) \geq 0.75d \times t \text{ when } 1.5d \leq d_o \leq 2d$$

$$t_i \leq 40 \text{ mm}$$

8.1.3 The provision of a thickened nozzle body protruding to both sides of the shell plate as shown in Fig. 9. The thickness of the nozzle shall be determined by reference to Fig. 5 such that $1.5 < j < 2$.

where j = stress concentration factor.

8.1.4 Other methods of reinforcement shall be the subject of agreement between the purchaser and the manufacturer.

8.1.5 The thickness of the manhole and nozzle bodies shall be not less than that given in Table 3.

TABLE 3. MANHOLE AND NOZZLE BODY THICKNESS

Outside diameter d_n	Min. 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

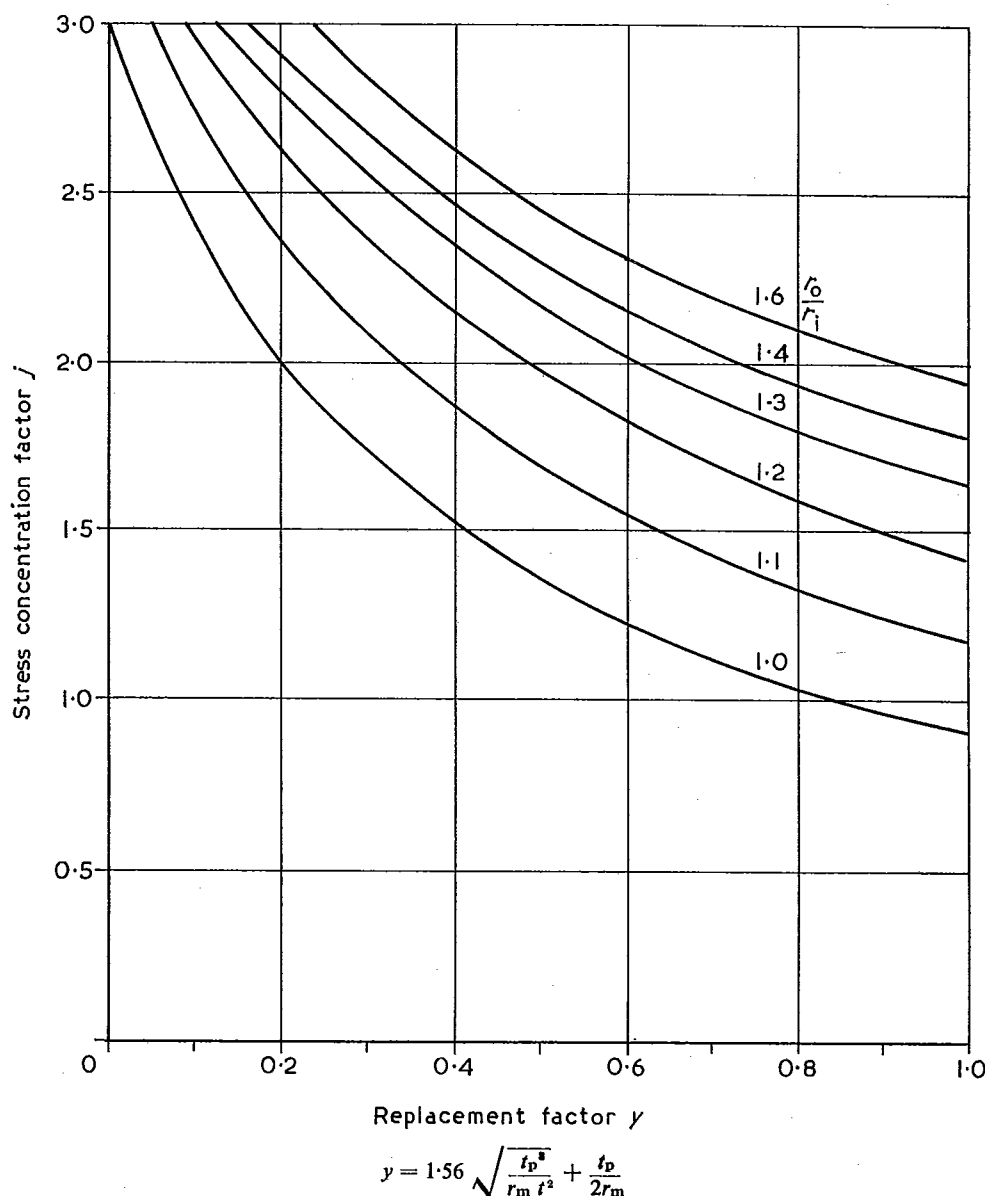


Fig. 5. Graph for the determination of the thickness of barrel type nozzle reinforcement (see 8.1.3) (Rose, R. T., Rim Reinforcement of Manholes, *British Welding Journal*, October, 1961)

8.2 Shell nozzles less than 80 mm outside diameter. These nozzles need no additional reinforcement, provided that the thickness of the body is not less than that given in Table 3. Set-on nozzles (see Figs. 14 and 15) 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.

8.3 Roof manholes and nozzles. 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 Fig. 10.

8.4 Nozzle welding details

8.4.1 Typical weld details for nozzles, manholes and other openings are shown in Figs. 11 to 16 and, unless otherwise agreed shall be limited to the forms of joint preparation illustrated.

8.4.2 The toes of fillet welds connecting the nozzle or reinforcing plates to the shell, or the centre line of butt welds connecting insert plates to the shell, shall not be closer than 150 mm to the centre line of any other shell butt-joint, the toe of the shell to bottom fillet weld, or the toe of fillet welds of adjacent attachments. The reinforcing plate or insert plate may be extended to the shell to bottom junction provided the plate intersects the bottom at 90° (see Fig. 17).

8.4.3 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 Figs. 11 to 13.)

8.4.4 Butt-joints connecting insert plates to the shell plates shall have full penetration and complete fusion.

8.4.5 The leg length of fillet welds around the periphery of reinforcing plates shall equal the thickness of the reinforcing plate or 19 mm, whichever is the less.

8.5 Inspection

8.5.1 The butt-welds connecting insert plates to the shell plate shall be fully radiographed. All fillet welds and butt welds which cannot be examined by radiography shall be fully wet magnetically crack detected before the hydrostatic test. Where applicable, crack detection shall be carried out before and after stress relief. Welds shall be ground to a sufficient extent to ensure that interpretation of the crack detection or radiography is not impaired.

8.5.2 When the thickness of nozzle bodies manufactured from rolled plate exceeds 19 mm that area of the body to be welded to the shell shall be ultrasonically examined for laminations, and a minimum layer of 3 mm of weld metal shall be applied to the surface of the body, prior to the welding of the nozzle to the shell (see Fig. 21).

8.6 Flange drilling. The flanges of all nozzles and manholes shall be made and drilled in accordance with Class 150 of BS 1560, Part 2,* unless otherwise agreed between the purchaser and the manufacturer.

8.7 Post-weld heat treatment

8.7.1 All mountings involving openings in the shell shall be furnace post-weld heat treated.

8.7.2 The width of the plate containing the mounting and its reinforcement shall be at least equal to the full width of the course and its length shall not be less than its width.

8.7.3 An extension pipe or flange welded to either the inside or outside of the nozzle and not forming part of the required reinforcement is not considered part of the assembly.

8.7.4 Subsequent welds to nozzles shall not be closer than $2.5 \sqrt{r_i t_p}$ to any weld which had been post-weld heat treated, where r_i is the inside radius of the pipe and t_p the wall thickness.

8.8 Procedure for post-weld heat treatment. The procedure of 8.8.1 to 8.8.8 shall be adopted for post-weld heat treatment.

8.8.1 The temperature of the furnace at the time the assembly is placed in it shall not exceed 400°C.

8.8.2 The rate of heating above 400°C shall not exceed the following:

Max. thickness of assembly up to and including 25 mm	200°C per hour.
Max. thickness of assembly over 25 mm	200°C per hour divided by 4 % of the max. thickness in mm or 50°C per hour, whichever is the greater.

8.8.3 During the heating period there shall not be a greater variation in temperature throughout the assembly being heated than 150°C and when at the holding temperature, the temperature throughout shall be within the range 580°C to 620°C.

* BS 1560, 'Steel pipe flanges and flanged fittings (nominal sizes ½ in to 24 in) for the petroleum industry', Part 2, 'Metric dimensions'.

8.8.4 During the heating and holding periods the furnace atmosphere shall be so controlled as to avoid excessive oxidation of the surface. There shall be no direct impingement of the flame on the assembly.

8.8.5 When the assembly has attained a uniform temperature as specified above, the temperature shall be held constant for a period in hours equal to 4 % of the thickness in mm of the shell plate with a minimum of one hour.

8.8.6 The assembly shall be cooled in the furnace to 400°C at a rate not exceeding the following:

Max. thickness of assembly up to and including 25 mm	250°C per hour.
Max. thickness of assembly over 25 mm	250°C per hour divided by 4 % of the max. thickness in mm or 50°C per hour, whichever is the greater.

Below 400°C the assembly may be cooled in still air.

8.8.7 The temperatures specified shall be actual temperatures of any part of the vessel and shall be determined by thermocouples attached to the assembly.

8.8.8 A sufficient number of temperatures shall be recorded continuously and automatically. Several thermocouples shall be applied to ensure that the whole assembly being heat treated is within the range specified.

8.9 Stairways and gangways

8.9.1 Stairways and gangways shall be of metallic construction and the minimum clear walking space shall be 600 mm.

8.9.2 It is recommended that the angle of stairways to the horizontal plane should not exceed 45°.

8.9.3 The stairway treads shall be of the non-slip type. The rise shall be 200 mm with a minimum width of 200 mm measured at the mid-length of tread.

8.9.4 Stairways and gangways if fixed to the shell shall be attached in accordance with 8.16.

8.9.5 Stairways and gangways shall be capable of supporting a superimposed load of 2.4 kN/m². It is recommended that, where the vertical rise of stairways is more than 6 m intermediate landing or landings should be provided.

8.9.6 Tank gangways which extend from one part of a tank to any part of an adjacent tank or to ground or other structure shall be so supported as to permit free relative movement of the structures joined by the gangway.

8.10 Handrailing

8.10.1 Handrailing to tank roofs, stairways and gangways shall be of solid steel sections and shall be designed to prevent personnel from falling.

8.10.2 Handrails shall be provided on both sides of gangways and stairways, also on circular and spiral stairways where the distance between the tank shell and the inner stringer is more than 200 mm.