

Specification for

**Manufacture of vertical steel
welded non-refrigerated
storage tanks with butt-welded
shells for the petroleum
industry**

Foreword

This British Standard was prepared under the direction of the Pressure Vessel Standards Policy Committee and replaces BS 2654 : 1984 which is now withdrawn. It is designed to provide the petroleum industry with tanks of adequate safety, reasonable economy and in a range of suitable capacities for the storage of oil and oil products. The committee recognizes, however, that this standard could be adopted with equal safety and economy by other industries and/or for the storage of other products, although purchasers and manufacturers may need to formulate and agree additional requirements necessitated by the conditions pertaining to a particular application.

NOTE. Users of this British Standard are reminded that the BSI committee responsible is prepared to offer interpretations of the text on request.

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. 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 have 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.

WWP test data all indicate that resistance to brittle fracture is dependent upon the following.

- (a) Notch toughness of the material.
- (b) Plate thickness.
- (c) 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.
- (d) 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.

The method specified is for determining the notch toughness required of a material in any given thickness for design temperatures down to -10°C based on tests in which through-thickness defects up to 10 mm long, located both in locally embrittled and post-weld heat treated material, are required to withstand approximately four times yield point strain (see figure 1).

Scale A is derived using these criteria and data from WWP tests for as-welded joints.

Scale B is used for determining the requirements for the hydrostatic test.

Appendix A gives recommendations for tank foundations and appendix B gives recommendations for the design and application of insulation.

This standard is expressed in metric units and a proposed range of standard metric diameters and capacities is given in appendix C.

All pressure and vacuum values in this standard are expressed as gauge values.

The symbols used throughout the text are as listed in appendix D.

Appendix E gives recommendations for internal floating covers, appendix F gives recommendations for the design of venting systems and appendix G offers seismic loading provisions.

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

This edition introduces technical changes to bring the standard up-to-date but it does not reflect a full review of the standard, which will be undertaken in due course.

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

Summary of pages

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Specification

1 Scope

This British Standard specifies requirements for the materials, design, fabrication, erection and testing of vertical cylindrical welded non-refrigerated steel tanks.

The standard applies specifically to the needs of the petroleum industry and the requirements for the design, construction, inspection and testing of tank shells apply when the design relative density of the product stored will not be less than 1.0.

NOTE 1. This provides the petroleum industry with the necessary operational flexibility in that tanks originally designed to store one particular product can subsequently be utilized to store products of differing relative densities when the need arises.

The standard applies to non-refrigerated storage tanks with the following characteristics:

- (a) maximum design pressure of 56 mbar*;
- (b) design metal temperature not cooler than -10°C ;
- (c) that are never filled above the level of the top of the cylindrical shell or the overflow, whichever is lower.

NOTE 2. For special cases outside the scope of this specification where the design pressure lies between 56 mbar and 140 mbar, reference may be made to BS 4741 for types of roof design procedures.

In addition to the definitive requirements, the standard also requires the items detailed in clause 3 to be documented. For compliance with this standard, both the definitive requirements and the documented items have to be satisfied.

NOTE 3. The titles of the publications referred to in this standard are listed on the inside back cover.

2 Design conditions

2.1 Design pressure (see 3.1(e))

2.1.1 General. In the interests of standardization of design pressures, storage tanks shall be grouped as specified in 2.1.2 to 2.1.4.

2.1.2 Non-pressure tanks. Non-pressure tanks shall be suitable for working at atmospheric pressure, but designed for an internal pressure of 7.5 mbar and a vacuum of 2.5 mbar. In all cases the tanks shall comply with 8.5. For tanks with column-supported roofs, an internal pressure of 4 mbar shall be assumed.

2.1.3 Low-pressure tanks. Low-pressure tanks shall be designed for an internal pressure of 20 mbar and a vacuum of 6 mbar.

2.1.4 High-pressure tanks. High-pressure tanks shall be designed for an internal pressure of 56 mbar and a vacuum of 6 mbar.

2.2 Design metal temperature (see 3.1(f))

The design metal temperature shall be specified by the purchaser on the basis of the official weather reports over at least 30 years. The design metal temperature shall be the lower of the lowest daily mean temperature† plus 10°C and the minimum temperature of the contents.

For a storage tank constructed for service in the UK where the shell temperature is controlled by ambient conditions, the minimum design metal temperature shall not exceed 0°C .

For a storage tank constructed for use outside the UK and where no long term data or weather reports are available, the design metal temperature shall be the lower of the lowest daily mean temperature† plus 5°C and the minimum temperature of the contents.

In the interests of operational flexibility, the minimum design temperature for the tank shall not take into account the beneficial effect of heated or insulated tanks.

3 Information to be exchanged prior to implementing the requirements of this standard and inspections by the purchaser during erection

3.1 Information to be specified by the purchaser‡

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

- (a) Geographical location of the tank.
- (b) Diameter and height or the capacity of the tank, including ullage. Where only the capacity of the tank is specified ground conditions shall be included.
- (c) Whether fixed or floating roof is to be supplied and the type of roof if the purchaser has specific preferences, i.e. for fixed roofs (cone, dome, membrane, etc.) or for floating roofs (pontoon, double deck, etc.).
- (d) All relevant properties of the contained fluid, including the relative density and corrosion allowance (if, how and where required).
- (e) The design vapour pressure and vacuum conditions inside the tank (see 2.1).
- (f) The minimum and maximum design metal temperatures (see 2.2).
- (g) The size, number and type of all mountings required showing locations. Maximum filling and emptying rates and any special venting arrangements (see 9.9).
- (h) The minimum depth of product (see 10.1(b)).
- (i) If the tank is to be insulated (see clause 12).

* 1 mbar = $100\text{ N/m}^2 = 100\text{ Pa}$.

† $\frac{1}{2}$ (maximum temperature + minimum temperature).

‡ Where the word 'purchaser' occurs in the text, it is intended to include representatives of the purchaser, e.g. purchaser's inspector.

(j) Areas of responsibility between the designer, the manufacturer and the erector of the tank when these are not the same.

(k) Quality of the water (particularly if inhibitors are to be present) to be used during tank water test (see 18.4.2).

(l) Expected maximum differential settlements during water testing and service lifetime of the tank (see appendix A).

(m) Other specifications which are to be read in conjunction with this standard.

3.2 Optional and/or alternative information to be supplied by the purchaser

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

(a) Whether a check analysis is required (see 4.3.2).

(b) Whether the weight of insulation is excluded from the minimum superimposed loadings (see 5.3.2).

(c) Whether significant external loading from piping, etc. is present (see 5.5).

(d) Whether seismic loading is present requiring specialist consideration including methods and criteria to be used in such analysis (see 5.7 and appendix G).

(e) Whether a fixed roof is required and if so:

(1) if cone roof slope is other than 1 in 5 (see 8.2.2);

(2) if radius of curvature of dome roof is other than 1.5 times tank diameter (see 8.2.2);

(3) whether made as a double-welded lap joint or a butt joint (see 8.3.5);

(4) whether particular venting requirements are specified (see 8.6.1 and 8.6.2).

or (f) Whether a floating roof is required and if so:

(1) whether floating roof is designed to land as part of the normal operating procedure (see 9.1.1);

(2) whether floating roof is designed for wind-excited fatigue loading (see 9.3);

(3) whether top edge of bulkhead is to be provided with continuous single fillet weld (see 9.5);

(4) floating roof ladder details (see 9.6.1, 9.6.2 and 9.6.4);

(5) type of primary roof drains (see 9.7.1);

(6) requirements for additional roof manholes (see 9.11);

(7) whether maximum aromatic content of the product is greater than 40 % (m/m) (see 9.13);

(8) requirements for the design of gauge hatch (see 9.14).

(g) An alternative type of manhole cover (see 11.3).

(h) Details of flange drilling if not in accordance with BS 1560 (see 11.7).

(i) Details of painting requirements and whether pickling, grit or shot blasting is required (see 13.6.1, 13.6.3 and 14.12).

(j) Details of erection marks (see 13.7.1).

(k) Whether welding electrodes and/or key plating equipment are to be supplied by the tank manufacturer (see 14.1).

(l) Alternative arrangements for provision of tank foundation (see 14.3).

(m) Whether a welder making only fillet welds is required to be approved for such welding in accordance with BS 4871 : Part 1 (see 16.3.2).

(n) Whether tack welding of shell, roof and bottom is permitted to be carried out by non-approved operators (see 16.3.2).

(o) Whether pneumatic testing of reinforcing plates is required (see 18.3.1).

3.3 Information to be agreed between the purchaser and the manufacturer

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

(a) Alternative materials selection (see 4.1).

(b) Precautions for avoiding brittle fracture during hydrostatic testing (see figure 1).

(c) Alternative bottom plate layouts (see 6.1.2).

(d) Spacing of the roof-plate-supporting members for dome roof (see 8.3.1).

(e) Any increase in roof joint efficiency for lapped and welded roof plates (see 8.3.6).

(f) Alternative loading conditions for floating roof design (see 9.2.1.4).

(g) The operating and cleaning position levels of the supporting legs (see 9.10.1).

(h) Proposed method to hold the plates in position for welding (but see 14.5.1).

(i) The location and number of checks on shell tolerances during erection (see 14.6.2).

(j) Methods of protecting the shell during erection against wind damage, etc. (see 14.9).

(k) If fixed roofs are to be erected in the tank bottom, and raised into position by an air pressure or suitable means (see 14.10).

(l) Sequence in which joints are to be welded (see 15.2).

(m) If previously approved appropriate welding procedures are acceptable (see 16.1.3).

(n) Test procedures to be used during the tank water test (see 18.1.1).

3.4 Inspections by the purchaser during erection

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

- (a) Rectification of damage to materials prior to erection (see 14.4).
- (b) Repair of all unacceptable defects found in welds (see 15.14.1).
- (c) Additional radiographic testing of welds (see 15.14.2).
- (d) Records of each welder's approval (see 16.3.5.1).
- (e) Standard test radiograph (see 17.4.4).
- (f) Repair of leaks in bottom and bottom to shell welds (see 18.2.4).
- (g) Leaks in pontoon compartments and decks (see 18.5.3).

4 Materials

4.1 Specifications

All materials used in the manufacture of tanks complying with this standard shall be in accordance with appropriate specifications given in either (a) or (b), and as amended or amplified by the requirements of this standard.

- (a) Plates, sections and bars: in accordance with BS EN 10025 and BS EN 10113 (ISO 630-1980*)
- Forgings: in accordance with BS 1503 (carbon and carbon/manganese steels only)
- Bolting material: in accordance with BS 1506
- Piping: in accordance with BS 3602 and BS 3603.

(b) Otherwise suitable materials agreed between the purchaser and the manufacturer (see 3.3(a)) provided that such materials are equivalent in heat treatment and chemical composition to those listed in (a) and, in other respects, comply with all the requirements of this standard.

NOTE. Examples are forgings in accordance with ASTM A105 : 1982†, piping in accordance with ASTM A106 : 1982† or ASTM A524 : 1980† or Grades A and B of API 5L : 1983‡.

4.2 Steelmaking process

Steels shall be made by the open hearth, electric furnace or one of the basic oxygen processes. Use of semi-killed or fully-killed steels shall be permitted provided that they comply with all the requirements of this standard. Neither

Bessemer steel nor rimming steel shall be permitted to be used.

The tank manufacturer shall ascertain from the steelmaker (at the time of order) the condition of supply of all plates, e.g. as-rolled, normalized, or quenched and tempered, and the nominal composition of the steel.

4.3 Chemical composition

4.3.1 The carbon equivalent calculated from the ladle analysis using the following formula shall not exceed 0.43 % (m/m) for plates 20 mm thick up to and including 25 mm nor 0.42 % (m/m) for plates thicker than 25 mm.

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

4.3.2 The ladle analysis and check analysis, when required (see 3.2(a)), shall be reported by the steel maker as required by the particular steel specification together with values for all elements specified in 4.3.1 and including any deliberate additions, e.g. aluminium, niobium, boron or vanadium. In a check analysis the carbon equivalent, using the formula $C + Mn/6$ shall not exceed 0.43 % (m/m) (see 3.2(a)). The incidence of testing shall not be less than that specified in BS EN 10025.

4.3.3 For steels with specified minimum tensile strength greater than 420 N/mm² the phosphorus plus the sulphur shall not exceed 0.08 % (m/m).

4.3.4 Steels shall be either aluminium treated with a minimum aluminium/nitrogen ratio of 2:1 or have a nitrogen content of less than 0.01 % (m/m).

4.4 Notch ductility

4.4.1 *General.* The required impact test temperatures and levels of impact properties for shell and bottom annular plates shall comply with the following clauses, as appropriate, together with 6.1.4 and figure 1:

- (a) clause 4.4.2 for materials ≤ 430 N/mm² tensile strength;
- (b) clause 4.4.3 for materials > 430 N/mm² and ≤ 490 N/mm² tensile strength;
- (c) clause 4.4.4 for materials > 490 N/mm² tensile strength.

For thicknesses not exceeding 13 mm in materials with specified minimum tensile strengths up to and including 490 N/mm², impact tests are not required.

NOTE. Steels may be supplied in conditions other than normalized when it is to be demonstrated to the satisfaction of the purchaser that the manufacturing procedure (e.g. controlled rolling, quenching and tempering, accelerated cooling, etc.) will provide equivalent notch ductility.

*When specifying ISO 630-1980, published by the International Organization for Standardization (ISO), it is recommended that reference is made to the appropriate national steel standard for the purposes of specifying additional requirements not included therein.

†Published by the American Society of Materials and Testing and available from the Library, BSI, Linford Wood, Milton Keynes MK14 6LE.

‡Published by the American Petroleum Industry and available from the Library, BSI, Linford Wood, Milton Keynes MK14 6LE.

4.4.2 Materials with specified minimum tensile strengths less than or equal to 430 N/mm², thicker than 13 mm. Materials with specified minimum tensile strengths less than or equal to 430 N/mm² and thicker than 13 mm shall be impact tested and show not less than 27 J Charpy V at +20 °C or at the test temperature indicated in figure 1, whichever is the lower. Three specimens shall be tested, the value taken being the minimum average of the three results. The minimum individual value shall be not less than 70 % of the specified minimum average value.

NOTE. Provided the design metal temperature is +10 °C or above, it is not necessary to test materials with a specified minimum yield strength not exceeding 300 N/mm² and less than 20 mm thick.

4.4.3 Materials with specified minimum tensile strengths greater than 430 N/mm² and up to and including 490 N/mm², thicker than 13 mm. Materials with specified minimum tensile strengths greater than 430 N/mm² and up to and including 490 N/mm² and thicker than 13 mm shall be impact tested and show not less than 41 J Charpy V at -5 °C or at the test temperature indicated in figure 1, whichever is the lower. Three specimens shall be tested, the value taken being the minimum average of the three results. The minimum individual value shall be not less than 70 % of the specified minimum average value.

4.4.4 Materials with specified minimum tensile strengths greater than 490 N/mm², all thicknesses. Materials with specified minimum tensile strengths greater than 490 N/mm² and of all thicknesses shall be impact tested and show not less than 41 J Charpy V at -15 °C or at the test temperature indicated in figure 1, whichever is the lower. Three specimens shall be tested, the value taken being the minimum average of the three results. The minimum individual value shall be not less than 70 % of the specified minimum average value.

4.5 Mountings

4.5.1 Reinforcing plates and insert plates shall have a minimum specified yield strength not less than 90 % of the

minimum specified yield strength for the shell plates to which they are attached. Nozzle bodies shall also comply with these requirements when the nozzle body is used in the reinforcement calculation.

4.5.2 Permanent attachments, reinforcing plates, insert plates, nozzle bodies and flanges shall comply with the notch ductility requirements of 4.4. The reference thickness shall be taken as the nominal thickness of the component except for the following.

(a) *Welding neck flanges.* The reference thickness shall be taken as the thickness at the weld or 25 % of the flange thickness, whichever is greater.

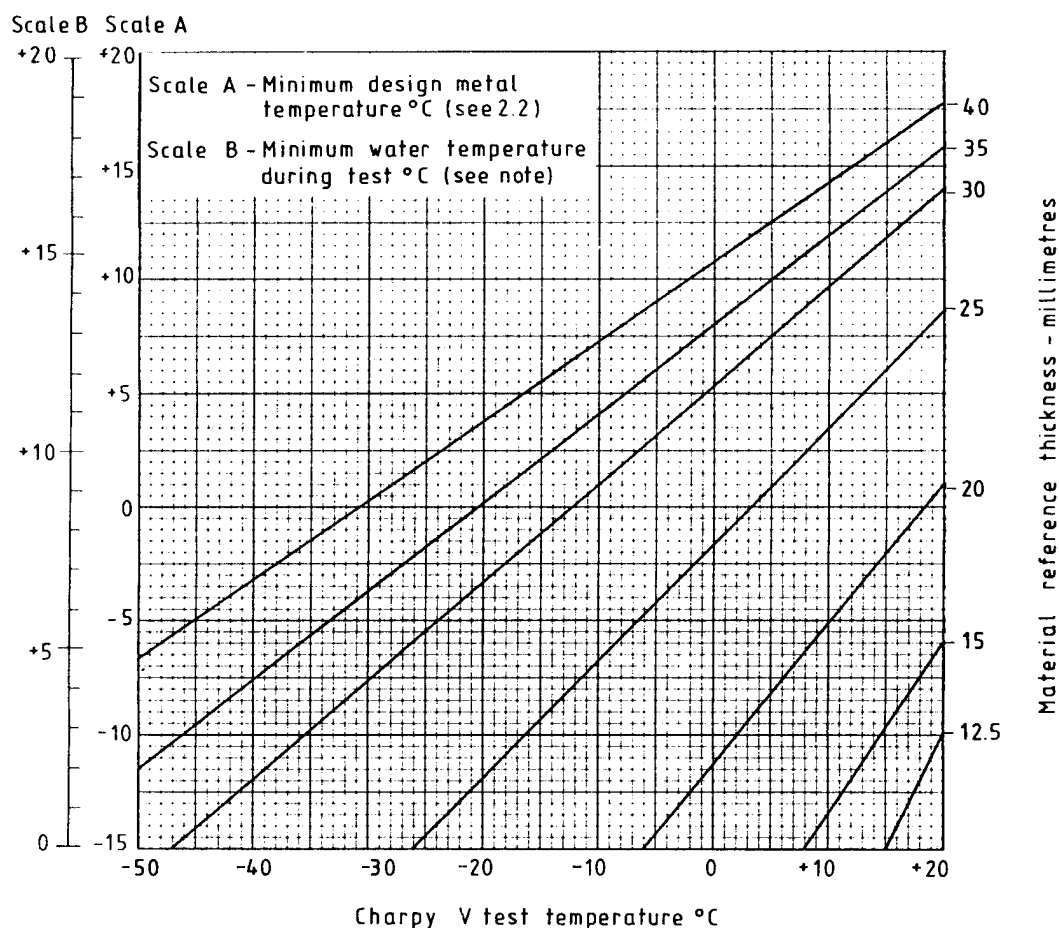
(b) *Hubbed or slip-on flanges.* The reference thickness shall be taken as the nominal thickness of the branch to which the flange is welded or 25 % of the flange thickness, whichever is greater.

(c) *Reinforcing plates.* The reference thickness shall be taken as its nominal thickness and if such plates exceed 40 mm thick, they shall show not less than 27 J Charpy V at -50 °C, irrespective of the minimum design metal temperature. Three specimens shall be tested, the value taken being the minimum average of the three results. The minimum individual value shall be not less than 70 % of the specified minimum average value.

4.6 Other requirements

4.6.1 The measured thickness at any point more than 15 mm from the edge of any shell (whose thickness shall comply with 7.1.3), bottom, roof or annular plate shall not be less than the specified thickness less half the total tolerance given in table of BS EN 10029, class D.

4.6.2 The measured thickness at any point more than 15 mm from the edge of shell plates whose thicknesses have been calculated in accordance with 7.2.2 to be greater than as specified in 7.1.3, shall not be less than the calculated minimum thickness, i.e. table 1 of BS EN 10029, class C.



(Intermediate values may be determined by interpolation.)

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 with specified minimum tensile strength greater than 430 N/mm²) value may be made on the basis of 1.35 J per °C, such extrapolation being 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 steel of specified minimum tensile strength greater than 400 N/mm², the equivalent test temperature for 27 J may be assumed to be -25 °C.

The requirements derived from scale A take into account an improvement in safety which may be anticipated as a result of the hydrostatic test. During the first hydrostatic test the degree of security against brittle fracture may be rather less than on subsequent loading. Attention is drawn to the more conservative requirements of scale B when consideration is to be given to the use of this scale during hydrostatic testing of tank shells constructed of steels with specified minimum tensile strength greater than 430 N/mm². The application of scale B, or any alternative procedure regarding the precautions to be taken during water testing to safeguard the tank from brittle fracture, is the subject of agreement between the purchaser and the manufacturer (see 3.3(b)).

Figure 1. Minimum Charpy V impact requirements

5 Design loadings

5.1 General

The tank shall be designed for the most severe possible combination of the loadings specified in 5.2 to 5.7.

5.2 Dead loads

Dead loads shall be considered as those resulting from the weight of all component parts of the tank.

5.3 Superimposed loads

5.3.1 The fixed roof and supporting structures shall be designed to support a minimum superimposed load of 1.2 kN/m^2 of projected area. The superimposed load shall be the sum of either internal vacuum and snow load, or internal vacuum and live load.

5.3.2 Unless otherwise specified by the purchaser (see 3.2(b)), the weight of any insulation shall be included in the minimum superimposed loadings for fixed roofs specified in 5.3.1.

5.3.3 The superimposed loadings applied to floating roofs shall be as specified in clause 9.

5.4 Contents

The load due to the contents shall be the weight of the product to be stored from full to empty, with or without the specified vapour pressure. For the design of the shell, the product relative density shall be assumed to be not less than 1.0.

5.5 Loads resulting from connected piping

Pipes, valves and other items connected to the tank shell shall be designed in such a manner that no significant additional loads or moments are applied to the tank shell.

Settlement of all pipe support foundations relative to those of the tank, rotational and translational movements of the lowest shell course shall be taken into consideration.

The purchaser shall state whether this loading is significant (see 3.2(c)), otherwise it shall not be taken into account.

5.6 Wind loading

The wind speed used in the calculations shall be the maximum three second gust speed estimated to be exceeded on the average only once in 50 years.

In the UK this value shall be taken as effective 'wind speed' as defined in BS 6399 : Part 2. In other areas the

three second gust speed shall be obtained from the appropriate authority.

NOTE. Careful consideration should be given to open-top water tanks without any form of roof since wind effects could produce severe movement of the contents resulting in spillage and excessive loading on the tank. If this loading cannot be quantified, it is recommended that a roof be provided unless previous experience with similar conditions has proved satisfactory.

5.7 Seismic loads (if applicable)

The purchaser shall specify whether the tank is to be designed to withstand seismic loads (see 3.2(d)).

NOTE. Recommendations on seismic provisions for storage tanks are given in appendix G.

6 Bottom design

6.1 General

6.1.1 Full support of the tank bottom by the foundation shall be assumed.

NOTE. Recommendations for tank foundations and typical tank pads are given in appendix A.

6.1.2 Bottoms for tanks up to and including 12.5 m diameter shall normally be constructed from rectangular plates, with sketch plates to the perimeter. In particular cases, by agreement between the purchaser and the manufacturer (see 3.3(c)), a ring of annular plates or other layouts are permitted. The specified thickness of the rectangular, sketch and annular plates shall be not less than 6 mm (see 4.6.1), excluding the corrosion allowance.

6.1.3 All tanks greater than 12.5 m diameter shall have a ring of annular plates having the following minimum thicknesses:

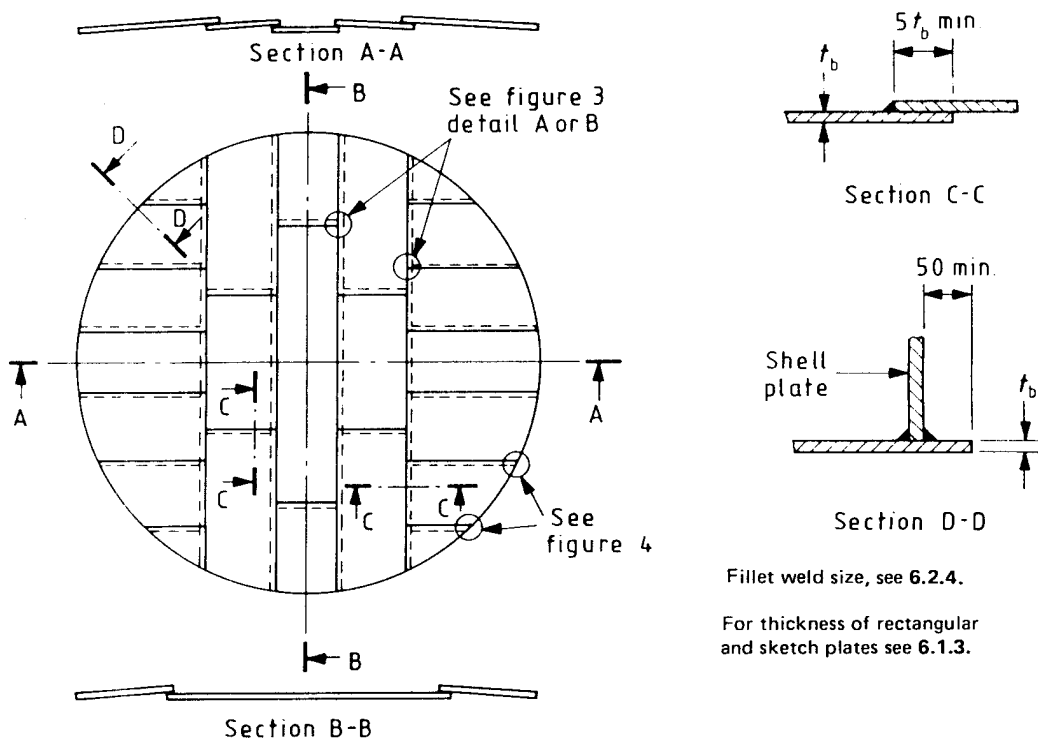
- (a) 8 mm, when the bottom course of shell plating is 19 mm thick or less;
- (b) 10 mm, when the bottom course of shell plating is over 19 mm up to and including 32 mm thick;
- (c) 12.5 mm, when the bottom course of shell plating is over 32 mm thick.

The specified thickness of both the rectangular plates and the sketch plates shall be not less than 6 mm (see 4.6.1).

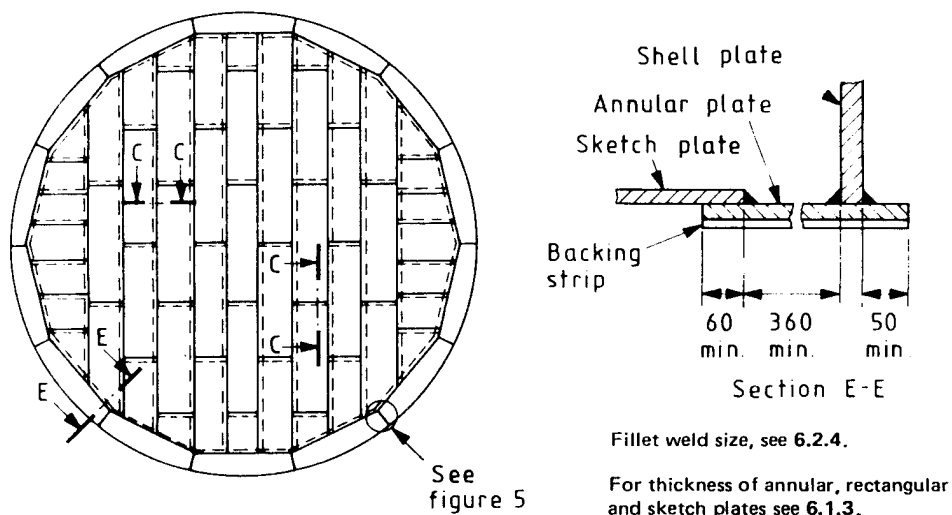
All thicknesses excluding the corrosion allowance.

6.1.4 The annular plates shall have a minimum width of 500 mm and shall be of the same material specification with respect to strength and impact requirements as the bottom course of shell plate.

6.1.5 The minimum distance from the outer surface of the shell plates to the outer edge of the bottom plates shall be in accordance with sections D—D and E—E of figure 2.



(a) Typical bottom layout for tanks up to and including 12.5 m diameter



(b) Typical bottom layout for tanks over 12.5 m diameter

For layout of plates similar to sections A—A and B—B see (a).
Dimensions are in millimetres, unless otherwise stated.

Figure 2. Typical bottom layouts for tanks (see clause 6)

6.2 Design

6.2.1 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 section C—C of figure 2).

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 section E—E of figure 2).

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 detail A or B of figure 3 as a corrective measure if the upper plate overlaps the lower plate.

6.2.2 For tanks of 12.5 m diameter and under, 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.

6.2.3 For tanks exceeding 12.5 m diameter, the radial seams connecting the ends of the annular segmental plates shall be full penetration butt-welded; a backing strip weld of the form shown in figure 5 is acceptable.

6.2.4 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 each fillet weld shall be equal to the thickness of the sketch plate or annular plate (see sections D—D and E—E of figure 2), except that they shall not exceed the appropriate value given in table 1 when the shell plate thickness is less than the bottom plate thickness.

Table 1. Leg length of fillet weld	
Shell plate thickness	Leg length of fillet weld
mm	mm
5	6
6 and over	8

In the design of high-pressure tanks (see 2.1.4), special consideration shall be given to the limitation of uplift in the tank bottom (see clause 10).

Typical layouts for tank bottom plates are shown in sections A—A and B—B of figure 2.

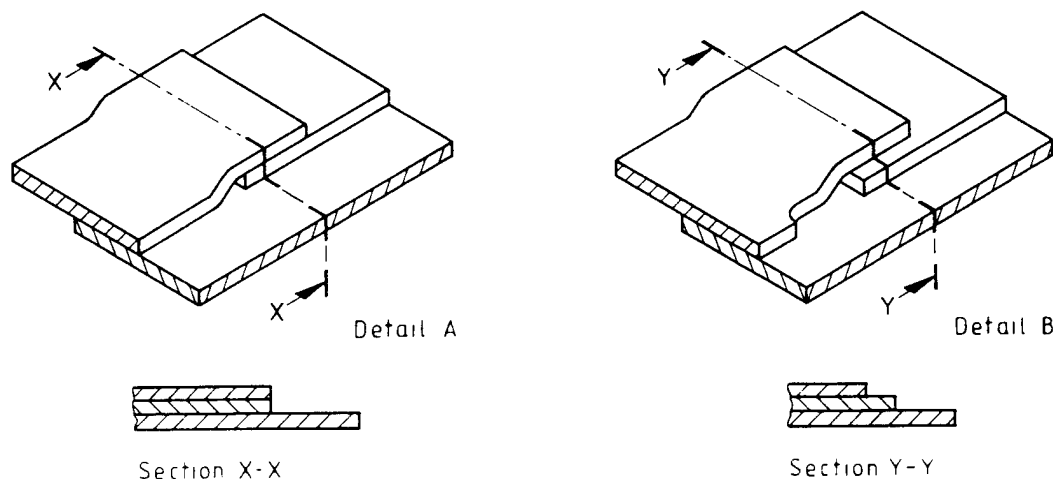
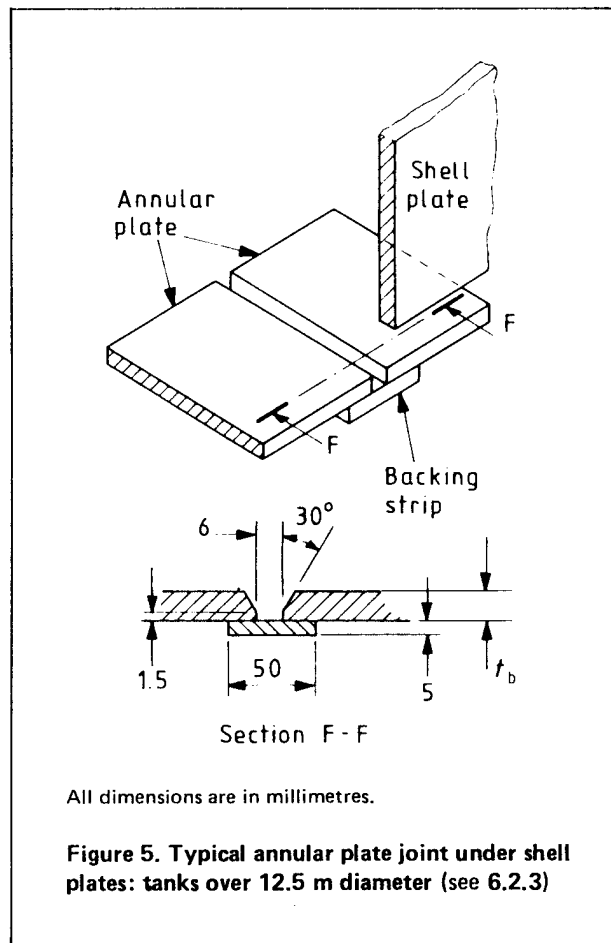
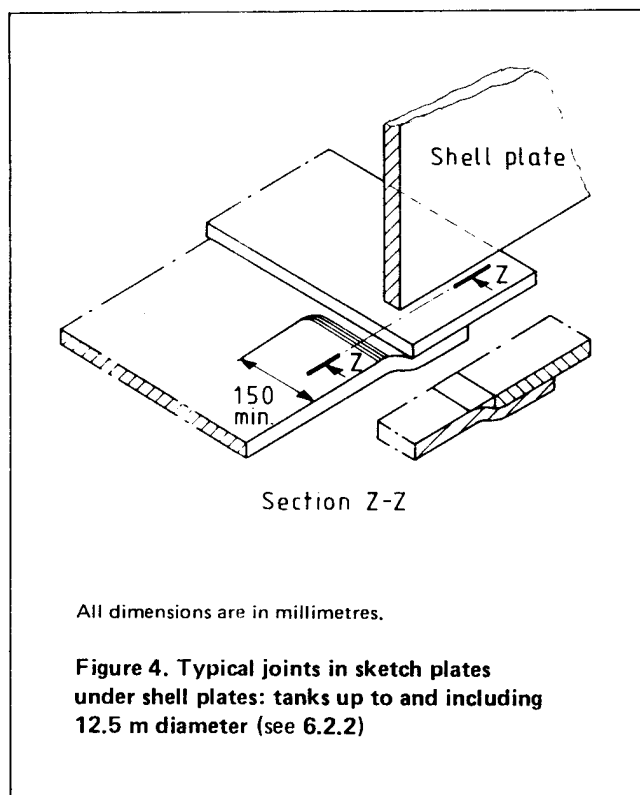


Figure 3. Cross joints in bottom plates where three thicknesses occur (see 6.2.1)



7 Shell design

7.1 Design stresses

7.1.1 The maximum allowable design stress in any plate shall be 260 N/mm^2 or two-thirds of the material specified minimum yield strength (in N/mm^2) at room temperature for all tank courses, whichever is the lower. Where the operating temperature is over 150°C , consideration shall be given to the effect of that temperature on the yield strength.

7.1.2 In calculating the thickness of plate required, the joint efficiency factor has been taken as 1.0. No relaxation shall be permitted to the requirements of this standard with regard to the approval of procedures and welders (see clause 16) and the site inspection of shell joints (see clause 17).

7.1.3 In no case shall the specified thickness of shell plates be less than is given in table 2 (see 4.6.1).

The maximum thickness of shell plates shall be 40 mm.

Table 2. Minimum specified shell thickness

Nominal tank diameter D	Specified shell thickness t
m	mm
$D < 15$	5
$15 \leq D < 30$	6
$30 \leq D < 60$	8
$60 \leq D < 75$	10
$75 \leq D < 100$	12
$100 \leq D$	14

NOTE. These specified 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 7.2.

For large-diameter tanks with low heights, the lowest shell course may be rather thin, so that the stability should be checked taking into account the vertical loadings and the possible uneven settlement of the foundations (see 9.2.3 of BS 5387 : 1976).

7.2 Internal loading

7.2.1 The tank shell thickness shall be computed on the assumption that the tank is filled either to the top of the shell or to the overflow designed to limit the fluid height. When the height of the shell includes a wind skirt with overflow openings and/or seismic freeboard, the maximum product height for calculation purposes shall be the overflow height or the height less the seismic freeboard.

The calculation shall be based on the relative density of the stored product and this shall not be less than 1.0.

7.2.2 The following formula shall be used in calculating the minimum thickness t (in mm) of shell plates (see 4.6.2):

$$t = \frac{D}{20S} \{98w(H - 0.3) + p\} + c$$

where

H is the distance from the bottom of the course under consideration to the height defined in 7.2.1 (in m);

D is the tank diameter (in m);

w is the maximum density of the contained liquid under storage conditions, but shall not be less than 1.0 (in g/mL);

S is the allowable design stress (see 7.1) (in N/mm²);

p is the design pressure (this can be neglected for non-pressure tanks) (in mbar);

c is the corrosion allowance (in mm).

7.2.3 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 and lower courses are made from materials with different mechanical properties and:

$$\frac{H_U - 0.3}{S_U} \geq \frac{H_L - 0.3}{S_L}$$

where

H_U is the distance from the bottom of the upper course to the height defined in 7.2.1 (in m);

S_U is the allowable design stress of the upper course (in N/mm²);

H_L is the distance from the bottom of the lower course to the height defined in 7.2.1 (in m);

S_L is the allowable design stress of the lower course (in N/mm²);

then the thickness of the upper course shall be calculated using the modified formula:

$$t = \frac{D}{20S} (98wH + p) + c.$$

Furthermore, no course shall be constructed at a thickness less than that of the course above, irrespective of the materials of construction.

7.3 Wind and vacuum loading

7.3.1 Primary wind girders

7.3.1.1 Open-top tanks shall be provided with a primary stiffening ring to maintain roundness when the tank is subjected to wind loads. The primary ring shall be located at or near the top of the top course and preferably on the outside of the tank shell.

7.3.1.2 Fixed-roof tanks with roof structure are considered to be adequately stiffened at the top of the shell by the structure, and a primary ring is not therefore considered necessary.

7.3.1.3 The required minimum section modulus of the primary stiffening ring Z (in cm³) shall be determined by the equation*:

$$Z = 0.058D^2H$$

where

D is the diameter of the tank (tanks in excess of 60 m in diameter shall be considered to be of this dimension when determining the section modulus) (in m);

H is the height of the tank shell including any 'freeboard' provided above the maximum filling height (see 7.2.1) (in m).

7.3.1.4 The section modulus of the primary stiffening ring shall be based upon the properties of the applied members.

NOTE 1. It may include a portion of the tank shell for a distance of 16 plate thicknesses below and, where applicable, above the ring shell attachment.

When curb angles are attached to the top edge of the shell ring by butt welding, this distance shall be reduced by the width of the vertical leg of the angle.

NOTE 2. Section moduli values for typical ring members are given in figure 6.

7.3.1.5 Stiffening rings shall comprise:

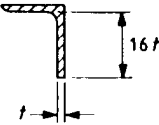
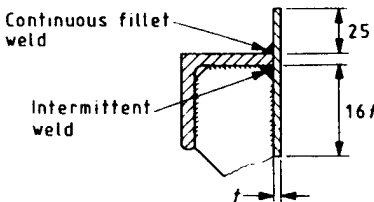
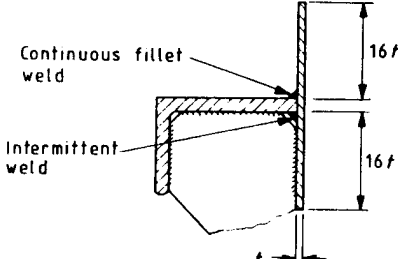
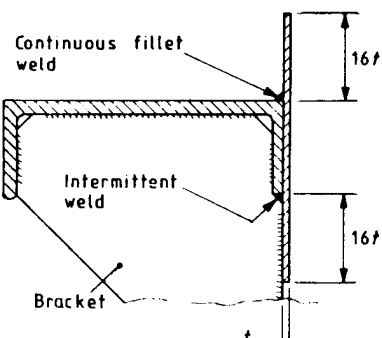
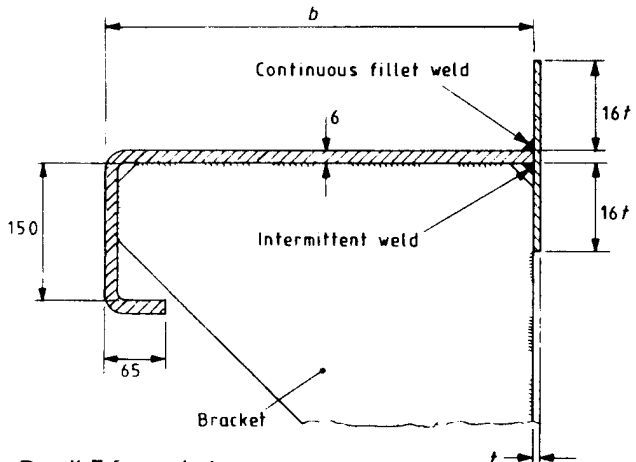
- (a) structural sections or formed plate sections; *or*
- (b) sections built up by welding; *or*
- (c) combinations of such types of sections assembled by welding.

NOTE. The outer periphery of stiffening rings may be circular or polygonal.

7.3.1.6 The minimum size of angle for use alone, or as a component in a built-up stiffening ring, shall be 60 mm × 60 mm × 5 mm. The minimal nominal thickness of plate for use in formed or built-up stiffening rings shall be 5 mm when its width does not exceed 600 mm and shall be 6 mm if over 600 mm wide.

7.3.1.7 When stiffening rings are located more than 600 mm below the top of the shell, the tank shall be provided with a 60 mm × 60 mm × 5 mm top curb angle for 5 mm top shell course and 80 mm × 80 mm × 6 mm angle for top shell course 6 mm and thicker.

*This equation is based on a wind velocity of 45 m/s (100 m.p.h.). If specified by the purchaser, other wind velocities (V in m/s) may be used by multiplying the equation by $(V/45)^2$.

Section through wind girder	Section modulus			
	Member size*	5 mm shell	6 mm shell	8 mm shell
		cm ³	cm ³	cm ³
Detail A top angle 	60 X 60 X 5	4.64	4.77	—
	60 X 60 X 6	5.50	5.64	—
	60 X 60 X 8	7.13	7.29	—
	70 X 70 X 8	9.70	9.90	—
	80 X 80 X 8	12.68	12.92	—
Detail B curb angle 	60 X 60 X 6	23.35	24.35	—
	70 X 70 X 6	31.88	33.24	—
	80 X 80 X 6	41.63	43.43	—
	90 X 90 X 6	52.69	54.98	—
	90 X 90 X 8	56.86	67.74	—
	100 X 100 X 8	65.80	82.41	—
Detail C single angle 	60 X 60 X 6	24.26	25.19	—
	60 X 60 X 8	29.70	31.06	—
	100 X 75 X 8	68.10	71.31	—
	100 X 75 X 10	79.26	83.43	—
	125 X 75 X 8	90.84	95.29	—
	125 X 75 X 10	106.38	112.07	—
	150 X 75 X 10	135.72	143.10	—
	150 X 90 X 10	153.09	161.45	—
Detail D channel 	178 X 76 (20.84 kg/m)	172.50	176.62	—
	203 X 76 (23.82 kg/m)	219.65	224.99	—
	229 X 76 (26.06 kg/m)	261.88	268.65	—
	254 X 76 (28.29 kg/m)	305.62	313.94	—
	254 X 89 (35.74 kg/m)	393.23	402.60	—
	305 X 89 (41.69 kg/m)	521.30	534.61	—
	305 X 102 (46.18 kg/m)	596.93	610.28	—
Detail E formed plate 	b = 250	—	341.02	374.81
	b = 300	—	427.22	473.07
	b = 350	—	518.73	577.15
	b = 400	—	615.46	686.89
	b = 450	—	717.38	802.18
	b = 500	—	824.41	922.93
	b = 550	—	936.56	1049.09
	b = 600	—	1053.80	1180.59
	b = 650	—	1176.12	1317.40
	b = 700	—	1303.50	1459.48
	b = 750	—	1435.94	1606.81
	b = 800	—	1573.43	1759.34
	b = 850	—	1715.96	1917.07
	b = 900	—	1863.53	2079.98
	b = 950	—	2016.13	2248.04
	b = 1000	—	2173.58	2421.24

*Mass per unit length given in parentheses, where appropriate.

Dimensions are in millimetres, unless otherwise stated.

Figure 6. Wind girders

7.3.1.8 Rings which may trap liquids shall be provided with adequate drain holes.

7.3.1.9 Stiffening rings or portions thereof which are regularly used as a walkway shall have a width of not less than 600 mm clear of the projecting curb angle on the top of the tank shell, shall be located 1 m below the top of the curb angle and shall be provided with hand railing on the otherwise unprotected side and at the ends of the section so used.

7.3.1.10 When a stairway opening is installed through a primary stiffening ring, adequate compensation shall be provided to ensure that the section modulus at any section through the opening complies with **7.3.1.3**.

The shell adjacent to such an opening shall be stiffened with an angle or bar placed horizontally. The other sides of the opening shall be stiffened with an angle or bar placed vertically. The cross-sectional area of these edge stiffeners shall be at least equivalent to the cross-sectional area of that portion of shell included in the section modulus calculation of the stiffening ring (see **7.3.1.4**). These stiffeners, or additional members, shall be positioned and designed so as to provide a suitable toe board around the opening. The stiffening members shall extend beyond the end of the opening for a distance equal to, or greater than, the minimum depth of the regular ring sections. The end stiffening members shall frame into the side stiffening members and shall be connected to them in such a manner as to develop their full strength.

7.3.1.11 Brackets shall be provided for all primary stiffening rings when the dimension of the horizontal leg or web exceeds 16 times the leg or web thickness. Such brackets shall be placed at intervals as required for the dead load and vertical live load that may be placed upon the ring. However, the spacing shall not exceed 24 times the width of the outside compression flange.

7.3.1.12 Continuous welds shall be used for all joints which, because of their location, might be subjected to corrosion from entrapped moisture. Full penetration butt welds shall be used for end-to-end joints in ring sections.

7.3.2 Secondary wind girders

7.3.2.1 In certain cases for both open-top and fixed-roof tank shells designed in accordance with this standard, secondary rings shall be required to maintain roundness over the full height of the tank shell under wind and/or vacuum conditions of loading.

7.3.2.2 Insofar as the primary ring is designed to stabilize the full tank height, the secondary rings are not required to carry panel loading, but are required to prevent preferential local buckling of the tank shell. The size of secondary rings as specified are not related to the design loads but shall be determined, with respect to tank diameter, in accordance with the values given in table 3.

Table 3. Angle ring dimensions

Tank diameter D	Angle ring (other shapes may be provided having equivalent modulus*)
m	mm
$D \leq 20$	100 x 65 x 8
$20 < D \leq 36$	125 x 75 x 8
$36 < D \leq 48$	150 x 90 x 10
$48 < D$	200 x 100 x 12
*The equivalent modulus is determined as for the primary rings as specified in 7.3.1.4 .	

The orientation and fixing of such secondary rings shall be as shown in detail B of figure 6.

7.3.2.3 Junctions between adjacent sections of the wind stiffeners shall develop the full strength of the angle at the point of junction.

Butt welds, if used, shall have complete penetration.

Whether or not adjacent sections are butt welded, the welding of such a joint shall be such that it produces fusion between the adjacent sections only and not fusion to the shell plate surface. Positive means to prevent such fusion shall be required, e.g. use of a mouse hole (approximately 20 mm radius).

7.3.2.4 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 shall determine the number of secondary rings required. In many cases these rings shall 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.

NOTE. The full analysis is best illustrated by way of the examples given in **7.3.2.7**.

A secondary ring shall not be located within 150 mm of a main circumferential tank seam.

7.3.2.5 The wind speed used in calculation shall be that specified in **5.6**.

7.3.2.6 The vacuum (v_a) to be used for the design of wind girders shall be as follows.

- 5 mbar, for open-top tanks irrespective of the design wind speed.
- 5 mbar, for non-pressure fixed-roof tanks, i.e. 2.5 mbar (design) setting, plus 2.5 mbar to allow accumulation for the vacuum valves to develop full design throughput.

(c) 8.5 mbar, for other fixed-roof tanks, i.e. 6 mbar (design) setting, plus 2.5 mbar to allow accumulation for the vacuum valve to develop full design throughput.

NOTE. A lower level of total vacuum may be used in the computation if this can be proven to be justifiable, e.g. with full-bore large free vents or low pumping rates on non-volatile storage.

7.3.2.7 The formulae to be used in the design of secondary wind girders shall be as follows.

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

$$H_E = \Sigma H_e$$

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

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

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 (corroded condition where applicable) (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).

Example 1. A floating-roof tank 95 m diameter, 20 m high having eight 2.5 m courses of thicknesses 12.0, 12.0, 14.2, 19.7, 24.7, 29.8, 34.9 and 39.9 mm is to be designed for a wind speed of 60 m/s. The primary ring is located 1.0 m from the tank top. How many secondary rings are required and what are their sizes and location?

Course	h m	t mm	H_e m
1	1.5	12.0	1.5000
2	2.5	12.0	2.5000
3	2.5	14.2	1.6412
4	2.5	19.7	0.7240
5	2.5	24.7	0.4113
6	2.5	29.8	0.2572
7	2.5	34.9	0.1733
8	2.5	39.9	0.1240
			$H_E = 7.3310$ m

$V_w = 60$ m/s, $v_a = 5$ mbar, so $K = 6.040644$

Hence

$$H_p = 6.040644 \sqrt{\frac{12^5}{95^3}} = 3.254 \text{ m}$$

Since $2H_p < H_E < 3H_p$, two secondary rings are required.

These are ideally located at $H_E/3$ and $2H_E/3$, i.e. 2.444 m and 4.888 m below the primary ring on the equivalent shell.

The upper ring is on a shell course of minimum thickness, so no adjustment of its location is needed.

The lower ring is not on a course of minimum plate thickness, so an adjustment is needed and its position below the primary ring shall be:

$$\{4.888 - (1.5 + 2.5)\} \sqrt{\left(\frac{14.2}{12.0}\right)^5} + 4.0 = 5.353 \text{ m}$$

The secondary rings are thus 2.444 m and 5.353 m below the primary ring, and are angles 200 mm x 100 mm x 12 mm.

Example 2. A fixed-roof non-pressure tank 48 m diameter 22.5 m high having nine 2.5 m courses of thicknesses 8, 8, 10.6, 14.3, 17.9, 21.6, 25.3, 29 and 32.6 mm is to be designed for a wind speed of 55 m/s. How many and what is the location and size of secondary rings?

Course	h m	t mm	H_e m
1	2.5	8.0	2.500
2	2.5	8.0	2.500
3	2.5	10.6	1.237
4	2.5	14.3	0.585
5	2.5	17.9	0.334
6	2.5	21.6	0.209
7	2.5	25.3	0.141
8	2.5	29.0	0.100
9	2.5	32.6	0.075
			$H_E = 7.681$ m

$V_w = 55$ m/s, $v_a = 5$ mbar, so $K = 6.945$

Hence

$$H_p = 6.945 \sqrt{\frac{8^5}{48^3}} = 3.780 \text{ m}$$

Since $2H_p < H_E < 3H_p$, two secondary rings are required.

These are ideally located $H_E/3$ and $2H_E/3$, i.e. 2.561 m and 5.122 m from the tank top.

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

The lower ring is not on a course of minimum plate thickness, so an adjustment is needed and its position from the tank top will be:

$$(5.122 - 5.0) \sqrt{\left(\frac{10.6}{8.0}\right)^5} + 5.0 = 5.250 \text{ m}$$

The secondary rings are therefore 2.561 m and 5.250 m from the top and are angles 150 mm x 90 mm x 10 mm.

Since the top stiffener comes within 150 mm of a horizontal seam, it has to be moved. Whether it is moved up say 211 mm to 2.35 m or down say 89 mm to 2.65 m from the tank top, the three portions of the tank are still stable against the design conditions as the positions resulting from moving the upper stiffener either up or down still gives a distance between the stiffeners less than H_p ($= 3.78$ m).

7.4 Shell plate arrangement

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

NOTE. 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.

7.5 Shell joints

7.5.1 All vertical seams shall be butt joints and shall have full penetration and complete fusion.

7.5.2 All horizontal seams shall be butt joints and, 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 approved (see clause 16).

NOTE. 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.

8 Fixed-roof design

8.1 Loads

Roofs shall be designed to support the loads specified in clause 5.

8.2 Type of roof

8.2.1 One of the two following types of roof shall be specified:

- (a) the self-supporting cone or dome roof; or
- (b) the column-supported roof.

NOTE. Column-supported roofs are not recommended to be used on foundations where significant settlement is anticipated unless special design provisions are made.

8.2.2 The roof slope of a cone roof shall either comply with the requirements specified by the purchaser (see 3.2(e)(1)) or be 1 in 5.

Where a domed roof is adopted, the radius of curvature shall either comply with the requirements specified by

the purchaser (see 3.2(e)(2)) or be 1.5 times the diameter of the tank.

NOTE. Normally the radius of curvature lies within the range 0.8 to 1.5 times the diameter of the tank.

Where a column-supported roof is used, a slope of 1 in 16 is recommended.

8.3 Roof plating with supporting structure

8.3.1 Roof-supporting structures (cone, dome or column supported) shall be designed in accordance with BS 449. The spacing of roof-plate-supporting members for cone roofs shall be such that the span between them does not exceed 2.00 m where one edge of the panel is supported by the top curb of the tank. Where this support is not present, the span shall not exceed 1.7 m. For dome roofs, this spacing shall be permitted to be increased as agreed between purchaser and manufacturer (see 3.3(d)).

8.3.2 Roof plates shall be continuously fillet welded to the top curb angle. For tanks exceeding 12.5 m diameter, roof plates shall not be attached to the roof-supporting structure.

8.3.3 The specified thickness of all roof plating shall be not less than 5 mm (see 4.6.1), excluding the corrosion allowance.

8.3.4 The steel used for construction of the roof members shall have a specified thickness of not less than 5 mm, excluding the corrosion allowance.

NOTE. This does not apply to the webs of rolled steel joists and channels or packings or to structures in which special provisions against corrosion are made.

8.3.5 Unless otherwise specified by the purchaser (see 3.2(e)(3)), plates shall be lapped and continuously fillet welded on the outside with a minimum lap of 25 mm.

NOTE. They should 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. Depending on the tank contents, it may sometimes be necessary for the lap joint to be double-welded or made as a butt joint.

8.3.6 The joint efficiency shall be taken as 1.0 for butt welds, 0.35 for lapped joints with fillet welds on one side only and 0.5 for lapped joints with fillet welds on both sides. The allowable stress shall be taken as two-thirds of the yield strength.

Increases in joint efficiency for a lap welded roof plate shall be permitted by agreement between the purchaser and the manufacturer (see 3.3(e)), provided that this can be justified by special procedure tests simulating the actual configuration to be used on site.

8.3.7 All roof framing shall be provided with bracing in the plane of the roof surface complying with the following.

- (a) Cross bracing in the plane of the roof surface shall be provided in at least two bays, i.e. between two pairs of adjacent rafters, on all roofs exceeding 15 m diameter. Sets 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 as follows:

- (1) roofs over 15 m up to and including 25 m diameter: one ring;
- (2) roofs over 25 m diameter: two rings.

8.4 Roof plating without supporting structure (membrane roofs)

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

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

For pressure:

$$t_r = \frac{pR_1}{20S\eta} \quad (\text{for spherical roofs})$$

$$t_r = \frac{pR_1}{10S\eta} \quad (\text{for conical roofs})$$

For buckling:

$$t_r = 40R_1 \sqrt{\frac{10P_e}{E}}$$

where

R_1 is the radius of curvature of roof (in m)
(for conical roofs, $R_1 = R/\sin\theta$; see figure 7);

P_e is the external loading plus self-weight of the plates (in kN/m^2);

E is Young's modulus (in N/mm^2);

p is the internal pressure (in mbar);

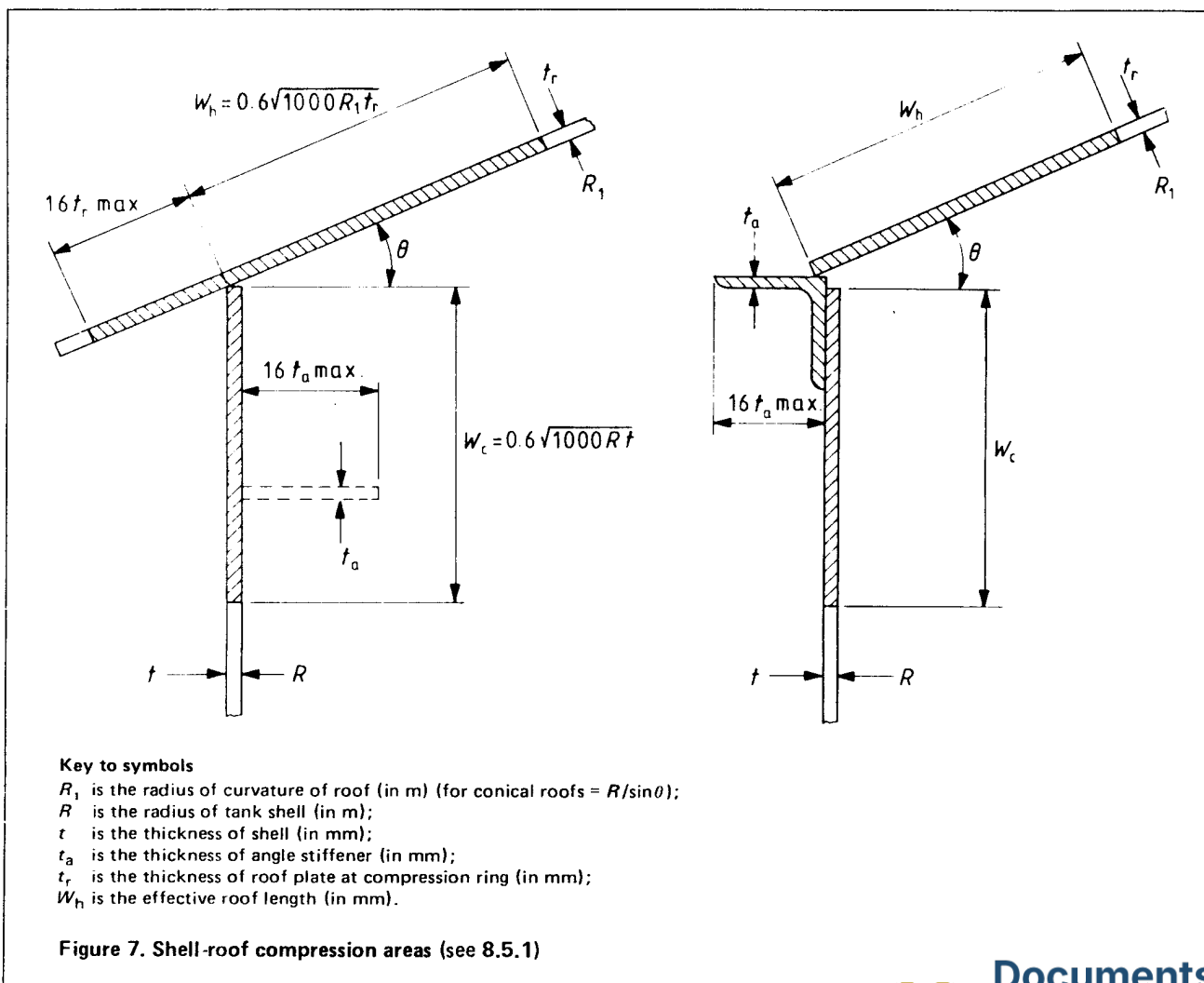
S is the allowable design stress (in N/mm^2);

t_r is the roof plate thickness (in mm);

η is the joint efficiency factor as specified in 8.3.6.

8.5 Compression area

8.5.1 The compression area is the region at the junction of the shell and the roof which is considered to resist forces imposed by the internal pressure and the maximum widths of plates making up the compression region shall be as shown in the shaded areas of figure 7.



8.5.2 The area to be provided A (in mm^2) shall be not less than that determined by the following equation:

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

where

- p is the internal pressure, see 2.1 (less weight of roof sheets) (in mbar);
- θ is the slope of roof meridian at roof-shell connection (see figure 7) (in degrees);
- R is the radius of tank (in m);
- S_c is the allowable compressive stress (which, unless otherwise specified, shall be taken as 120 N/mm^2) (in N/mm^2).

8.5.3 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 at a distance always less than the effective shell length for compression area W_c (see figure 7).

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

8.5.5 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.

8.5.6 For fixed-roof tanks the minimum area defined by A in 8.5.2 or the minimum sizes of top curb angle given in table 4, whichever is the greater, shall be provided.

Table 4. Minimum sizes of top curb angle	
Tank diameter D	Size of curb angle
m	mm
$D \leq 10$	60 × 60 × 6
$10 < D \leq 20$	60 × 60 × 8
$20 < D \leq 36$	80 × 80 × 10
$36 < D \leq 48$	100 × 100 × 12
$48 < D$	150 × 150 × 10

8.6 Venting requirements

8.6.1 General. The precise requirements for the venting of fixed-roof tanks designed to this standard shall be either particularly specified by the purchaser (see 3.2(e)(4)) or as specified in 8.6.2 to 8.6.4 inclusive.

8.6.2 Scope of venting provided. The venting system provided shall cater for the following:

- (a) normal vacuum relief;
- (b) normal pressure relief;
- (c) emergency pressure relief.

In the case of (c), this shall be specified in accordance with this standard unless disregarded at the purchaser's discretion (see 3.2(e)(4)). Where emergency pressure relief is required, it shall be provided by suitable vents or by the provision of a frangible roof joint (see F.3).

8.6.3 Venting capacity. The number and size of vents provided shall be based on the venting capacity obtained from appendix F and shall be sufficient to prevent any accumulation of pressure or vacuum exceeding the values specified in 8.6.4.

NOTE. These valves may be fitted with coarse-mesh screens to prevent the ingress of birds. The use of fine-mesh screens as anti-flash protection is not recommended because of the danger of blockage, especially under winter conditions.

Consideration should be given to the possibility of corrosion when selecting material for the wire mesh screen.

8.6.4 Accumulation of pressure and vacuum

8.6.4.1 In accordance with 7.3.2.6, the set vacuum plus the accumulation to permit the valves to achieve the required throughput shall not exceed v_a .

8.6.4.2 In accordance with 2.1, the set pressure plus the accumulation to permit the valves to achieve the required throughput for normal pressure relief shall not exceed the design pressure.

8.6.4.3 No specific values for emergency pressure accumulation are specified in this standard but the following considerations shall apply.

- (a) If it is expected that the design pressure specified in 2.1 is to be exceeded by the emergency pressure accumulation, then it shall be verified that the strength of the roof-to-shell junction is adequate and whether tank anchorage is required.

NOTE. This particularly applies to column-supported cone roof tanks with a low roof slope and to small tanks in general.

- (b) The set pressure of relieving devices for emergency conditions (if required) shall be consistent with the provisions of F.5.2.

- (c) Account shall be taken of the substantial differences between the opening and closing pressures (blowdown) that can occur between vents of different types.

NOTE. This standard does not cater for protection against over-pressure caused by explosion within the tank, and where such protection is to be provided special consideration should be given to the design of the tank and the venting devices.

9 Floating-roof design

9.1 General

9.1.1 A floating roof, being a structure designed to float on the surface of the liquid in an open top tank and to be in complete contact with that surface, shall comply with 9.2 to 9.15.

NOTE. This clause is not applicable to the design of floating covers installed in fixed-roof tanks in accordance with appendix E.

The requirements of this clause, unless otherwise qualified, shall apply only to the pontoon type and double-deck type of floating roofs which shall be differentiated as follows:

- (a) a pontoon type roof has a continuous annular pontoon divided by bulkheads into liquid-tight pontoon compartments and has a central area covered by a single-deck diaphragm;

(b) a double-deck roof has both an upper and a lower deck extending over the area of the liquid surface, the lower deck in contact with the liquid surface being separated from the upper deck by rim plates and bulkhead plates to form liquid-tight pontoon compartments.

In normal operation, the roof shall remain in the floating condition and shall only be landed on to its support legs for maintenance or inspection purposes. The purchaser shall specify whether the floating roof is to be designed to land as part of the normal operating procedure (see 3.2(f)(1)), otherwise this requirement does not apply.

9.1.2 The roof and accessories shall be so designed and constructed as to allow the tank to overflow and then return to a liquid level which floats the roof well below the top of the tank shell without damage to any part of the roof, tank or appurtenances. This requirement shall apply under both service and hydrostatic testing conditions.

If a winds skirt or top-shell extension is used for the purpose of containing the roof seals at the highest point of travel, overflow drainage openings shall be provided to indicate the rise of the liquid level in the tank above the designed capacity height, unless the tank shell has been designed for a liquid height to the top of the shell extension.

9.1.3 The specified thickness of all roof plating shall be not less than 5 mm (see 4.6.1).

NOTE. A corrosion allowance is not normally specified for floating roofs but if it is, the design should be checked in both corroded and uncorroded conditions.

9.2 Design requirements

9.2.1 Buoyancy

9.2.1.1 General. The roof shall comply with 9.2.1.2, 9.2.1.3 or 9.2.1.4, as appropriate.

9.2.1.2 Single-deck pontoon roofs. The design of single-deck pontoon roofs shall comply with the following.

(a) The minimum pontoon volume of a single-deck pontoon roof shall be sufficient to keep the roof floating on a liquid with a relative density not exceeding 0.7 if the single deck and any two pontoon compartments are punctured and the primary roof drain is considered as inoperative.

(b) The minimum pontoon volume of a single-deck pontoon roof shall be sufficient to keep the roof floating on a liquid with a relative density not exceeding 0.7 if it carries a load of 250 mm rainfall over the entire roof area concentrated on the centre deck and the primary roof drain is considered as inoperative. No pontoon compartments or centre deck shall be considered to be punctured for this condition.

9.2.1.3 Double-deck roofs. The design of double-deck roofs shall comply with the following.

(a) The minimum pontoon volume of a double-deck roof shall be sufficient to keep the roof floating on a liquid with a relative density not exceeding 0.7 if any two pontoon compartments are punctured and the primary roof drain is considered inoperative.

(b) The minimum pontoon volume of a double-deck roof shall be sufficient to keep the roof floating on a liquid with a relative density not exceeding 0.7 if it

carries a 250 mm rainfall over the entire roof area in a 24 h period and the primary roof drain is considered to be inoperative.

NOTE. Such a requirement may be satisfied by designing the roof to carry the entire 250 mm rainfall or alternatively a lower load may be assumed provided adequate emergency drains are fitted which will discharge the excess rainwater directly into the product.

When emergency drains are fitted, they shall not permit the product to flow on to the roof.

9.2.1.4 Alternative loading conditions. By agreement between the purchaser and the manufacturer (see 3.3(f)), it shall be permitted to design the roof for a fixed specific gravity, a fixed product, or a specified amount of rainfall deviating from the requirements of 9.2.1.2 and 9.2.1.3.

9.2.2 Structural design. The roof shall be designed to be structurally sound under the following loading conditions.

(a) Buoyancy conditions as specified in 9.2.1.

(b) When the roof is landed on its support legs and with a superimposed load of 1.2 kN/m² (the superimposed load is not intended to include any accumulated rainwater).

9.3 Stability of roof under wind load

The purchaser shall advise the manufacturer when tanks are to be erected in areas where wind conditions could give rise to fatigue loading which could result in centre deck weld cracks in normal pontoon type roofs, particularly for tanks over 50 m diameter, and the design and type of roof to be used shall be as specified by the purchaser (see 3.2(f)(2)). Otherwise, no account shall be taken of wind-excited fatigue loading.

9.4 Pontoon openings

Each compartment shall be provided with a manway with a rain-tight cover. The manway covers shall be so designed that they will re-seat if lifted by any gusts and not blow off under the specified wind conditions.

The top edge of manway necks shall be at an elevation to prevent water entering the compartments under the conditions specified in 9.2.

9.5 Bulkheads

Either all internal bulkhead plates shall be at least single-fillet welded along their bottom and vertical edges for liquid tightness, or when specified by the purchaser (see 3.2(f)(3)), the top edge of the bulkhead shall also be provided with a continuous single-fillet weld for liquid tightness.

Bulkhead plate corners trimmed for passage of longitudinal fillet welds shall be filled by welding to obtain liquid tightness.

9.6 Movable ladders to roofs

9.6.1 Unless otherwise specified by the purchaser (see 3.2(f)(4)), the floating roof shall be supplied with a ladder which automatically adjusts to any position of the

roof in such a manner as always to provide access to the roof. The ladder shall be designed for full roof travel, regardless of normal setting of roof-leg supports. If a rolling ladder is furnished, it shall have full-length handrails on both sides and shall be designed for a 500 kg vertical midpoint load with the ladder in any operating position combined with the maximum wind load acting in any direction of the ladder.

NOTE. Consideration should also be given to the vibration effects of wind loading and torsional rigidity of long ladders which can lead to the derailing of the ladder.

9.6.2 The ladder shall be equipped with self-levelling treads unless specified by the purchaser (see 3.2(f)(4)) that fixed rungs are to be used.

NOTE 1. When fixed rungs are used, it is recommended that safety wire netting should be provided on the underside of the ladder.

NOTE 2. Attention is drawn to the need for careful selection of heights for small-diameter tanks to permit the use of movable ladders.

9.6.3 The ladder shall run over a track, which shall be at such a height over the deck that snow or ice will not cause derailment of the ladder.

For long and heavy ladders, special attention shall be given to the bearing width of the rails and the strength of the wheels.

9.6.4 Unless otherwise specified by the purchaser (see 3.2(f)(4)), flameshields are not required to be fitted to ladders. If flameshields are fitted, the effect of the increased wind loading shall be considered in the design of the ladder and track.

9.7 Primary roof drains

9.7.1 Primary roof drains shall be of the hose or articulated-pipe type unless otherwise specified by the purchaser (see 3.2(f)(5)).

NOTE. If specified by the purchaser, open type roof drains may be used on double-deck roofs.

Roof drains shall be capable of operating under all specified service conditions of the roof.

9.7.2 A check valve shall be provided near the roof end of the hose, or articulated-pipe drains shall be provided on single-deck pontoon roofs, to prevent backflow of stored product on to the roof in case of leakage in the hose or the jointed pipe.

9.7.3 Provisions shall be included to prevent kinking of the hose or pinching under the deck legs.

Hose drains shall be designed to permit replacement without entering the tank.

9.7.4 The articulated joints of pipe drains shall be designed to prevent leakage, both of water into the product and vice-versa.

9.7.5 The installation of either type of drain shall include the installation of the proper shell fittings for its operation and, if necessary, its removal.

9.7.6 The minimum size primary drain shall be equivalent in capacity to the following:

- (a) one 75 mm drain for roofs up to and including 30 m in diameter;
- (b) one 100 mm drain for roofs more than 30 m in diameter;
- (c) one 150 mm drain for roofs more than 60 m in diameter.

9.8 Emergency drains

NOTE 1. *Pontoon roofs.* Open emergency drains should not be installed in pontoon type roofs as the product level in the tank is always higher than the rainwater level on the centre deck.

A 100 mm diameter emergency drain plug shall be located near the centre of the roof to permit the drainage of water when the roof is landed on its support legs.

NOTE 2. To prevent backflow of the product, measures should be taken to avoid this drain plug being opened in service.

NOTE 3. *Double-deck roofs.* Open type emergency drains may be installed at the centre of double-deck roofs which will discharge rainwater directly into the product (see also 9.2.1.3(b)).

9.9 Vents

The purchaser shall specify maximum liquid filling and withdrawal rates and any special venting requirements (see 3.1(g)).

Suitable vents shall be provided to prevent overstressing of the roof deck or seal membrane. These vents or bleeder valves shall be adequate to evacuate air and gases from underneath the roof during initial filling and when the product is being withdrawn with the roof landed on its support legs. Operating legs for such vents shall be adjustable to suit the various level settings of the roof-support legs.

9.10 Supporting legs

9.10.1 *Design of supporting legs.* Floating roofs shall be provided with supporting legs. Legs fabricated from pipe shall be provided with a 50 mm x 25 mm notch at the bottom to provide drainage. When variable roof levels are required, the legs shall be adjustable from the top side of the roof. The operating and cleaning position levels of the supporting legs shall be agreed between purchaser and manufacturer (see 3.3(g)).

The manufacturer shall make certain that all tank appurtenances, such as side-entry mixers, interior piping and filling nozzles, are cleared by the roof in its lowest position.

The design of the supporting legs shall not allow product to flow on to the roof deck when the roof is loaded with the maximum specified rainfall.

9.10.2 *Loading.* Legs and attachments shall be designed in accordance with BS 449 to support the roof and a live load of 1.2 kN/m². Where possible, roof loads shall be transmitted to the legs through bulkheads or diaphragms.

NOTE. These loadings do not make provision for any oil or water load or the possible effects of frequent landing of the roof (see also 9.1.1).

9.10.3 Distribution of leg loads. Measures shall be used, such as steel pads, to distribute the leg loads on the bottom of the tank. If used, pads shall be continuously welded to the bottom plates; shim plates, also continuously welded to the bottom, shall be used when these pads coincide with lap joints in bottom plates.

9.11 Roof manholes

At least one roof manhole shall be provided for access to the tank interior and for ventilation when the tank is empty. Any additional roof manholes shall be specified by the purchaser (see 3.2(f)(6)). These manholes shall be at least 500 mm inside diameter (i.d.) and shall have tight-gasketed and bolted covers.

9.12 Centering and anti-rotation device

Suitable devices shall be provided to maintain the roof in a centred position and to prevent its rotation. These devices shall be capable of resisting the lateral forces imposed on them by the roof ladder, unequal snow loads, wind loads, etc.

9.13 Seals

The space between the outer periphery of the roof and the tank shell shall be sealed by a flexible device which shall provide a reasonably close fit to the shell surfaces.

If the sealing device employs steel shoes in contact with the shell, such shoes shall be made from either stainless steel or galvanized sheet with a minimum thickness of 1.5 mm.

An adequate number of expansion joints shall be provided to aid the efficiency of the sealing.

Adequate means shall be provided to prevent an electrical charge on the floating roof causing sparking in or above the seal. In the case of seals with jointed mechanisms in the vapour space, a shunt shall be provided between the roof and shoe plate at every such mechanism.

Any fabric or non-metallic material used as a seal or a seal component shall be durable in its environment and shall not discolour or contaminate the product stored. The purchaser shall specify the maximum aromatic content of the product which the fabric is required to resist, if greater than 40 % (m/m) (see 3.2(f)(7)).

The manufacturer shall specify the maximum inward and outward movement of which the seal is capable.

9.14 Gauging device

Each roof shall be provided with a gauge hatch or gauge well with a tight cap either as specified by the purchaser (see 3.2(f)(8)) or to the manufacturer's own standard.

9.15 Operation

9.15.1 The design conditions specified in 9.2 shall not be considered as normal operating conditions but, as the ultimate conditions for flotation of the roof.

9.15.2 When primary roof drains are closed in winter, measures shall be taken to prevent the freezing of rainwater

in the lowest part of the roof drain outside the lowest shell course.

NOTE. The manufacturer should supply the purchaser with an operating and maintenance manual which should set out the design and operational limitations of the floating roof and should include at least the following points.

- (a) Pontoon compartments and centre decks should be checked for leaks at regular intervals; such leaks reduce the water-carrying capacity of the roof.
- (b) If the primary roof drain is normally kept closed when the roof is floating, rainwater should not be allowed to accumulate on the roof but in any case the roof drain should be opened when water equivalent to about 75 mm rainfall has collected.
- (c) If the primary roof drain is normally kept open, frequent inspections should be made to ensure that leaking articulated joints or punctured hoses are not permitting the product to escape through the drain.
- (d) When the product temperature is expected to be less than 0 °C, the roof drain should be drained of entrapped water and then closed and the precautions outlined in (c) observed.
- (e) The purchaser should ensure that the recommendations set out in such a manual are carefully observed by his operator.

10 Tank anchorage

10.1 General

Tank anchorage shall be provided for fixed roof tanks if, with one of the following conditions, there may be a tendency for the shell and the bottom plate, close to the shell, to lift off its foundations.

- (a) Uplift on an empty tank due to internal design pressure counteracted by the effective weight of roof and shell.
- (b) Uplift due to internal design pressure in combination with wind loading counteracted by the effective weight of roof and shell, plus the effective weight of product considered by the user to be always present in the tank (see 3.1(h)).

Tank weights shall be considered after deducting any corrosion allowance.

10.2 Anchorage attachment

The anchorage shall not be attached to the bottom plate only but principally to the shell. The design shall accommodate movements of the tank due to thermal changes and hydrostatic pressure and reduce any induced stresses in the shell to a minimum.

NOTE. A typical example is shown in figure 8 but other design details are permissible.

10.3 Allowable tensile stress

For the design conditions given, the allowable tensile stress in the anchorage shall not exceed one-half of the specified minimum yield strength or one-third of the minimum tensile strength, whichever is the lower.

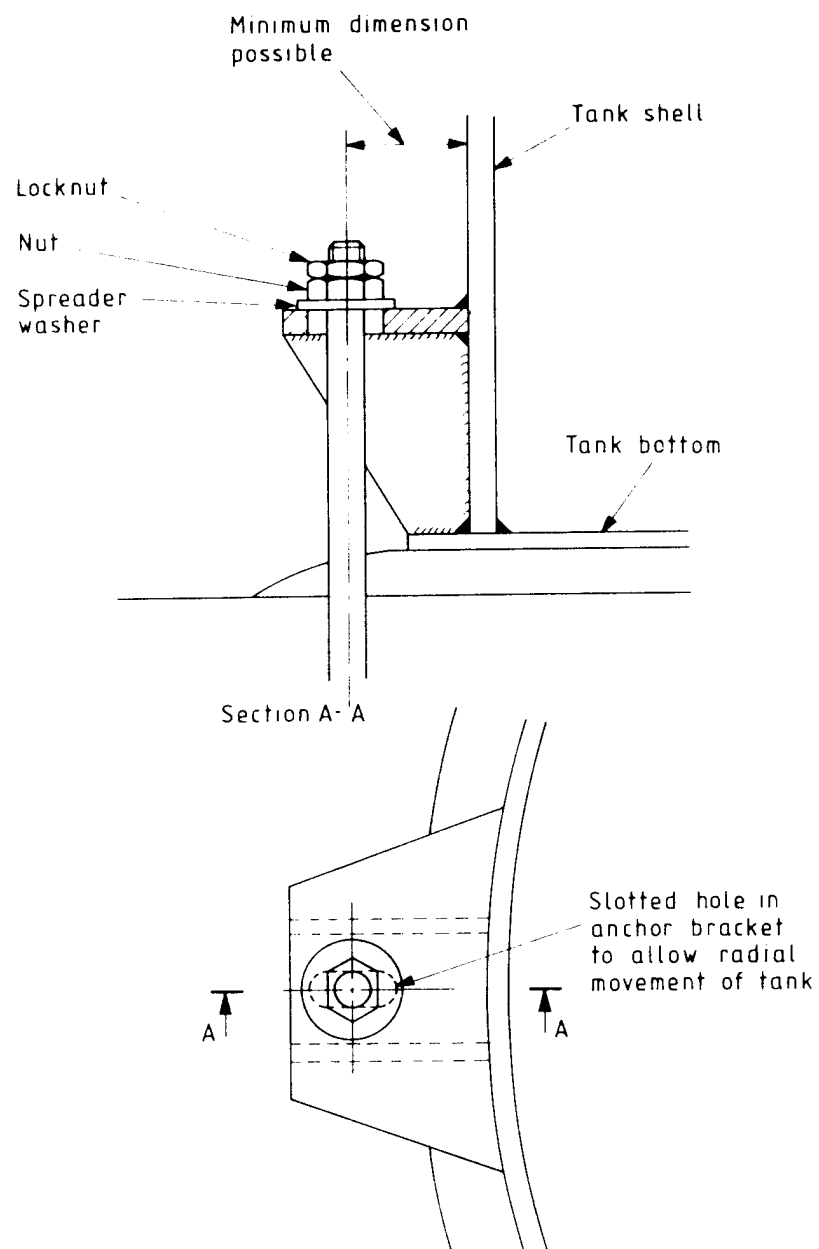


Figure 8. Typical tank anchorage detail (see 10.2)

10.4 Holding-down bolt or strap

Each holding-down bolt or strap shall have a minimum cross-sectional area of 500 mm² and, if corrosion is anticipated, a minimum corrosion allowance of 1 mm, e.g. 2 mm on diameter, shall be added.

NOTE. It is recommended that anchorage points are spaced at a minimum of 1 m and at a maximum of 3 m intervals and should as far as possible be spaced evenly around the circumference.

10.5 Resistance to uplift

The anchorage shall be capable of resisting the uplift produced by the test loads applied to the tank. For this condition the stress in the anchorage shall not exceed 0.85 times the specified 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.

NOTE. It is recommended that no initial tension be applied to the anchorage, so that it becomes effective only 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.

11 Mountings

11.1 Shell manholes and shell nozzles 80 mm outside diameter (o.d.) and above

11.1.1 The thickness of the manhole and nozzle bodies shall be not less than that given in table 5.

NOTE. The typical details of shell manholes for tanks not exceeding 25 m in height are given in figure 9.

11.1.2

11.1.2.1 Reinforcement shall be provided as specified in either 11.1.2.2 or 11.1.2.3.

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

$$0.75 d \times t$$

where

d is the diameter of the hole cut in the shell plate (in mm);

t is the thickness of the shell plate (in mm).

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

(a) The addition of a thickened shell insert plate (see figure 10 and figure 23), or a circular reinforcing plate, the limit of reinforcement being such that:

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

where

d_o is the effective diameter of reinforcement (in mm).

A non-circular reinforcing plate may be used provided the minimum requirements are complied with.

(b) The provision of a thickened nozzle or manhole body. The portion of the body which 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 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 7.2 subject to the limits specified in 7.1.3. The limit of reinforcement is that described in (a).

11.1.2.3 As an alternative to the area replacement methods specified in 11.1.2.2, the reinforcement can be made by the provision of thickened nozzle body protruding to both sides of the shell plate as shown in figure 11. The thickness of the nozzle is to be determined by reference to figure 12 such that the stress concentration factor j does not exceed 2.

Table 5. 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

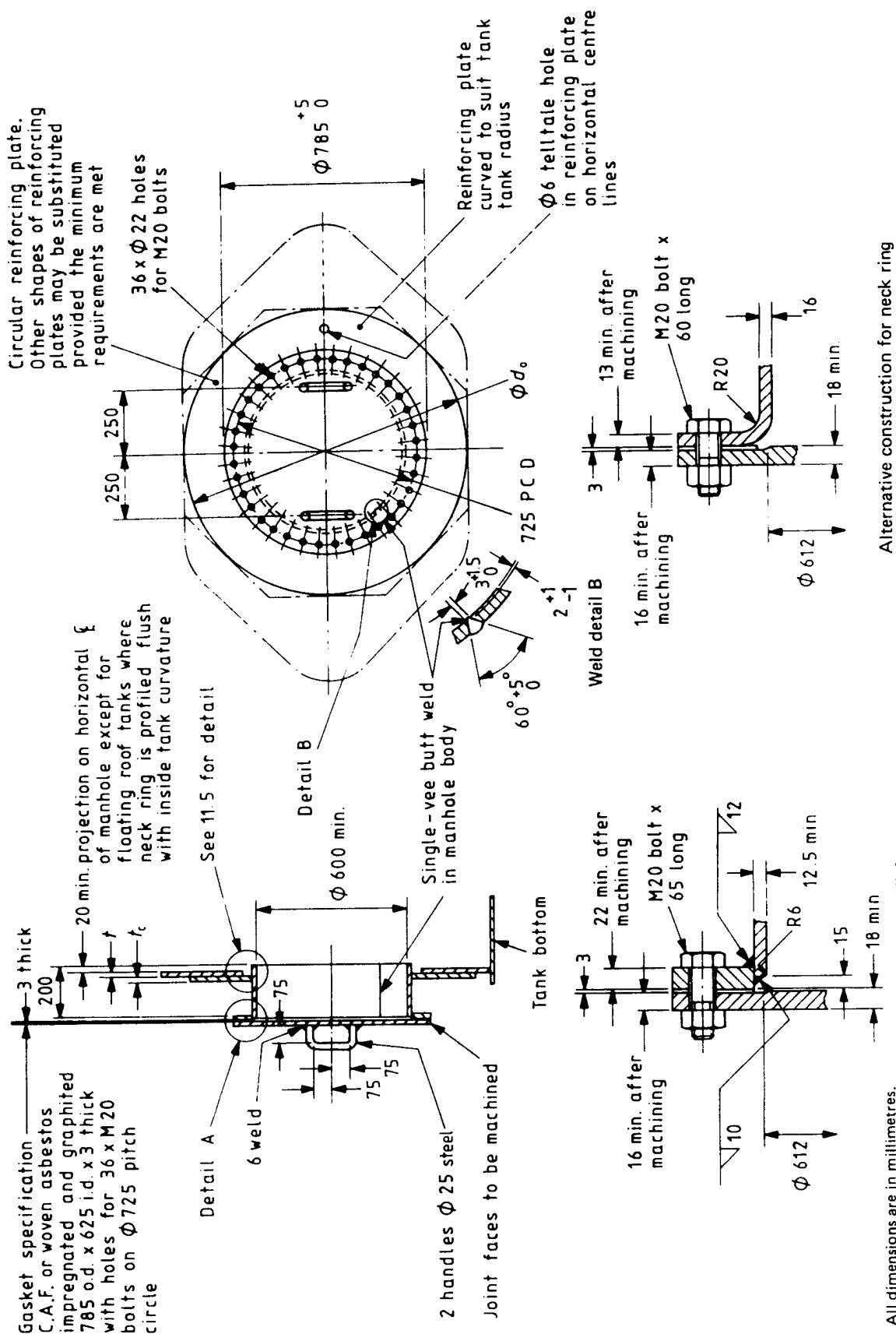


Figure 9. Shell manholes (see 11.1)

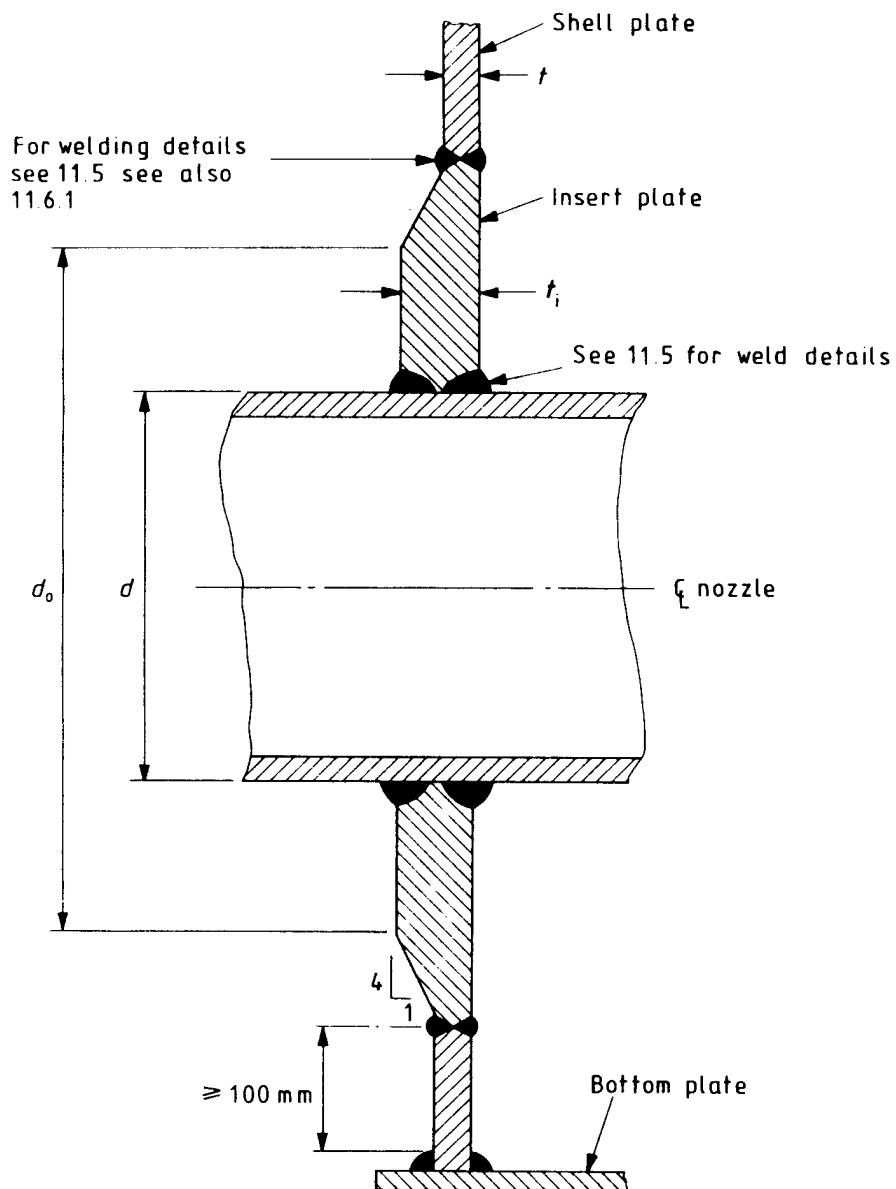


Figure 10. Shell insert type reinforcement (see 11.1.2.2)