British Standard

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BRITISH STANDARD

BS 2654:1989

Incorporating Amendment No. 1

Specification for

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

Committees responsible for this British Standard

The preparation of this British Standard was entrusted by the Pressure Vessels Standards Policy Committee (PVC/-) to Technical Committee PVE/15, upon which the following bodies were represented:

Associated Offices Technical Committee
British Chemical Engineering Contractors' Association
British Compressed Gases Association
British Gas plc
British Steel Industry
Energy Industries Council
Engineering Equipment and Materials Users' Association
Institution of Gas Engineers
Institution of Mechanical Engineers
Process Plant Association
Welding Institute

This British Standard, having been prepared under the direction of the Pressure Vessels Standards Policy Committee, was published under the authority of the Board of BSI and comes into effect on 29 September 1989

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Part 2 First published December 1961
Part 3 First published September 1968
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The following BSI references relate to the work on this standard:
Committee reference PVE/15
Draft for comment 87/77053 DC

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Amendments issued since publication

Amd. No.	Date of issue	Comments
9297	January 1997	Indicated by a sideline in the margin

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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prepared under the direction of the Pressure Vessel Standards Policy Committee and replaces BS 2654:1984 which is now withdrawn.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.

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

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

Summary of pages

This document comprises a front cover, an inside front cover, pages i to viii, pages 1 to 90, an inside back cover, and a back cover.

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

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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[1];

b) design metal temperature not coolar 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[2] 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 [2] 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[3]

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.).

[1] 1 mbar = 100 N/m^2 = 100 Pa.

[2] ½ (maximum temperature + minimum temperature).

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

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**).

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 inhibiters 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 4871-1 (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,	in accordance with BS EN 10025 and BS EN 10113
sections and bars:	(ISO 630-1980[a])
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.

[a] 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.

NOTE Examples are forgings in accordance with ASTM A105:1982[4)], piping in accordance with ASTM A106:1982[4)] or ASTM A524:1980[4)] or Grades A and B of API 5L:1983[5)].

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 steels 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.

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

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

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

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, niobiurn, 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/mm^2 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/mm^2 tensile strength;

b) clause **4.4.3** for materials > 430 N/mm^2 and ≤ 490 N/mm^2 tensile strength;

c) clause **4.4.4** for materials > 490 N/mm^2 tensile strength.

For thicknesses not exceeding 13 mm in materials with specified minimum tensile strengths up to and including 490 N/mm^2, 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.

4.4.2 *Materials with specified minimum tensile strengths less than or equal to* 430 N/mm^2, *thicker than* 13 mm. Materials with specified minimum tensile strengths less than or equal to 430 N/mm^2 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/mm^2 and less than 20 mm thick.

4.4.3 *Materials with specified minimum tensile strengths greater than* 430 N/mm^2 *and up to and including* 490 N/mm^2, *thicker than* 13 mm. Materials with specified minimum tensile strengths greater than 430 N/mm^2 and up to and including 490 N/mm^2 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/mm^2, *all thicknesses.* Materials with specified minimum tensile strengths greater than 490 N/mm^2 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.

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 6399-2. 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;

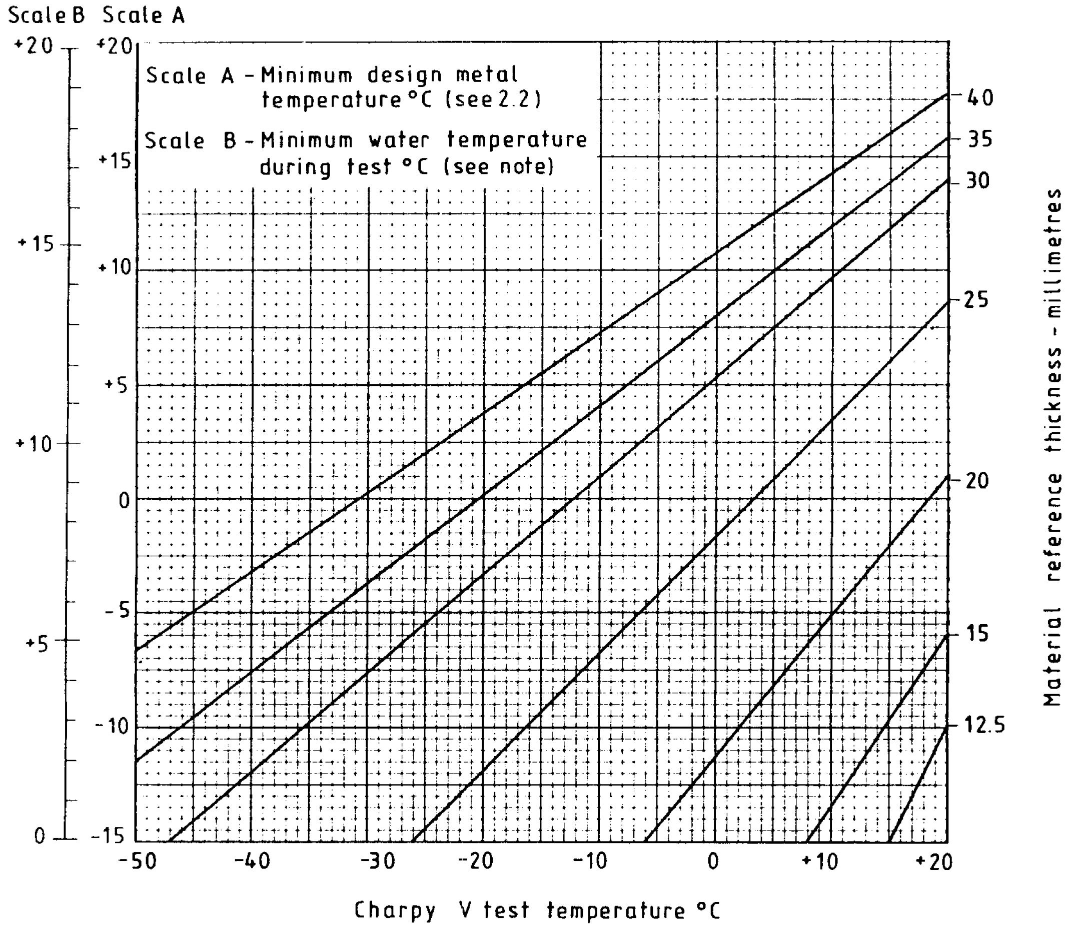
b) 10 mm, when the bottom course of shell plating is over 19 mm up to and including 32 mm thick;

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.

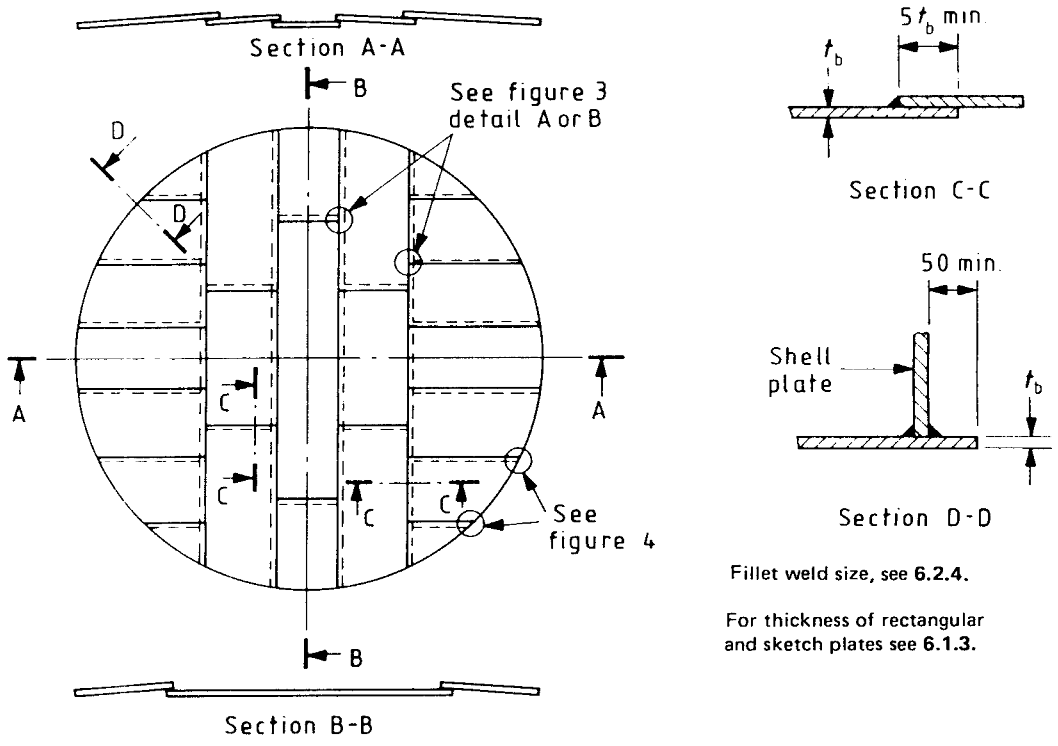
6.1.5 The minimum distance from the outer surface of the shell plates to the outer edge of the bottom plates shall be in accordance with sections D–D and E–E of Figure 2.



(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)].

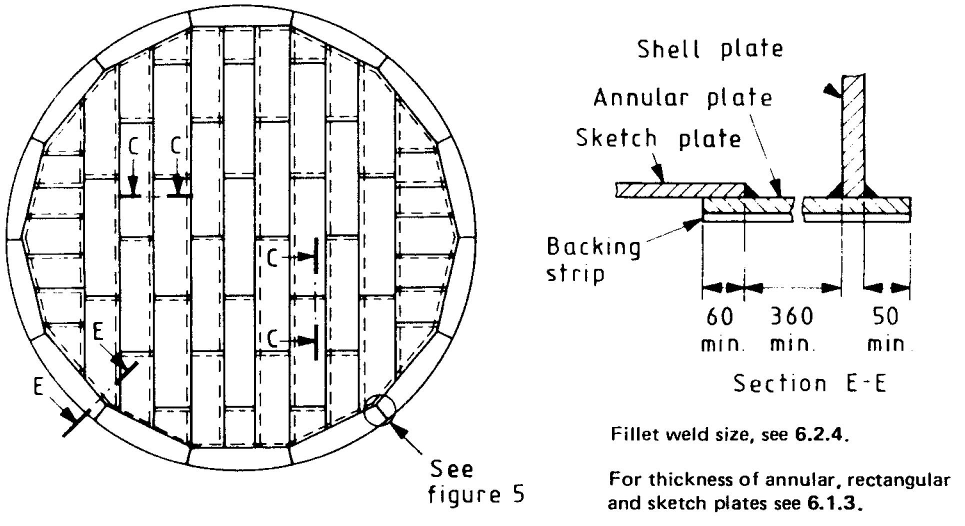
Figure 1 — Minimum Charpy V impact requirements



Fillet weld size, see **6.2.4.**

For thickness of rectangular and sketch plates see **6.1.3.**

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



Fillet weld size, see **6.2.4.**

For thickness of annular, rectangular and sketch plates see **6.1.3.**

(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.

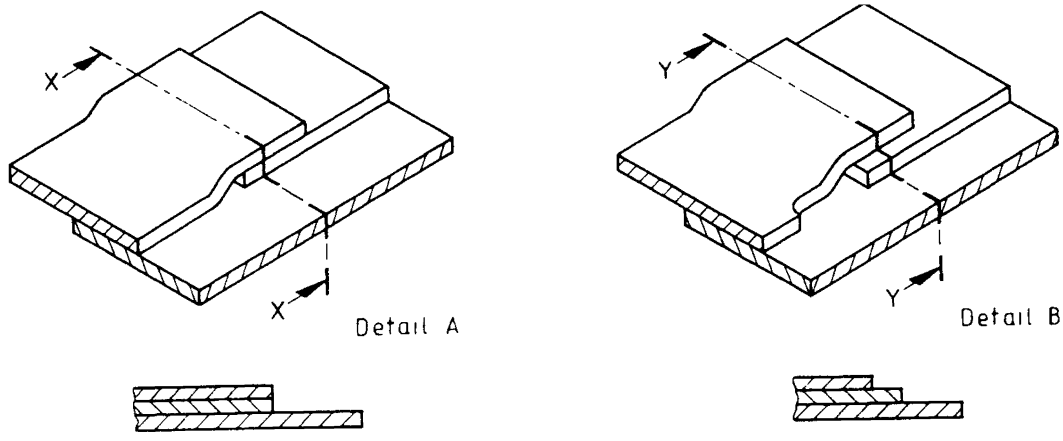
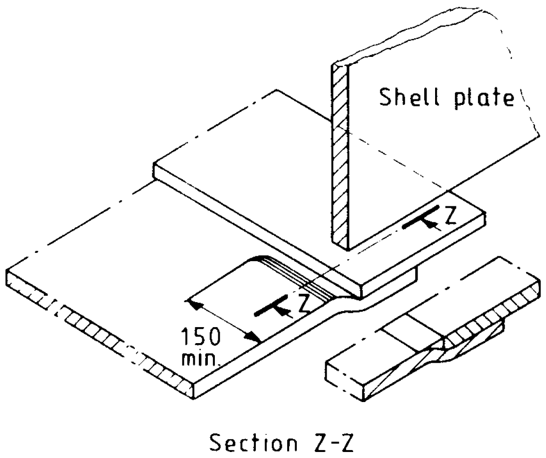
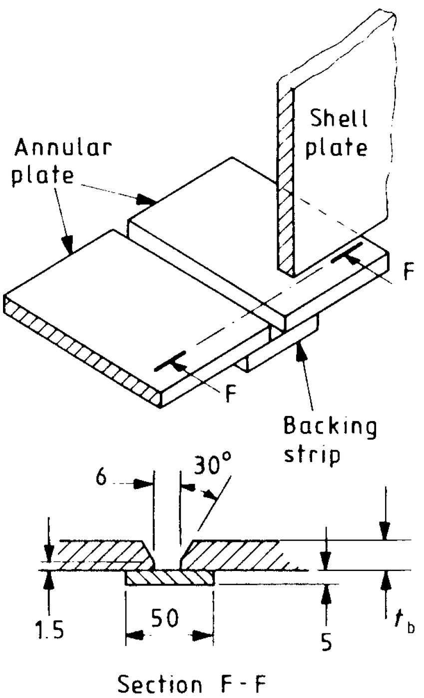


Figure 3 — Cross joints in bottom plates where three thicknesses occur (see **6.2.1**)



All dimensions are in millimetres.

Figure 4 — Typical joints in sketch plates under shell plates: tanks up to and including 12.5 m diameter (see **6.2.2**)



All dimensions are in millimetres.

Figure 5 — Typical annular plate joint under shell plates: tanks over 12.5 m diameter (see **6.2.3**)

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
$15 \le D < 30$	6
$30 \le D < 60$	8
$60 \le D < 75$	10
$75 \le D < 100$	12
$100 \le D$	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**):

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

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/mm^2);

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/mm^2);

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/mm^2);

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 cm^3) shall be determined by the equation[6]:

$$Z = 0.058D^2\,H$$

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*

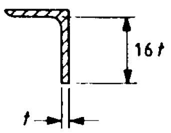
c) combinations of such types of sections assembled by welding.

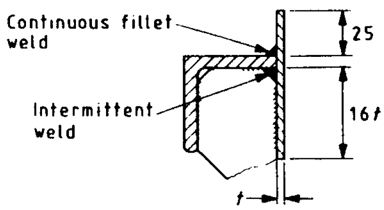
NOTE The outer periphery of stiffening rings may be circular or polygonal.

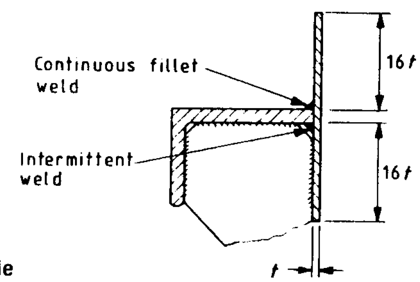
7.3.1.6 The minimum size of angle for use alone, or as a component in a built-up stiffening ring, shall be 60 mm × 60 mm × 5 mm. The minimal nominal thickness of plate for use in formed or built-up stiffening rings shall be 5 mm when its width does not exceed 600 mm and shall be 6 mm if over 600 mm wide.

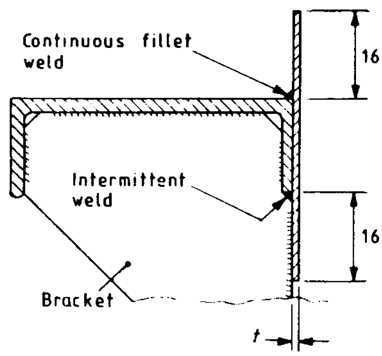
7.3.1.7 When stiffening rings are located more than 600 mm below the top of the shell, the tank shall be provided with a 60 mm × 60 mm × 5 mm top curb angle for 5 mm top shell course and 80 mm × 80 mm × 6 mm angle for top shell course 6 mm and thicker.

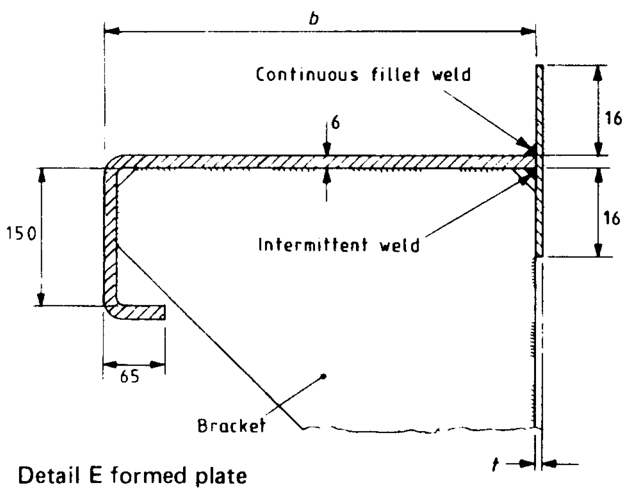
[6] This equation is based on a wind velocity of 45 m/s (100 m.p.h.). If specified by the purchaser, other wind velocities [*V* (in m/s)] may be used by multiplying the equation by $(V/45)^2$.











Section through wind girder	Section modulus			
	Member size[a]	5 mm shell	6 mm shell	8 mm shell
		cm^3	cm^3	cm^3
Detail A top angle	60 × 60 × 5	4.64	4.77	—
	60 × 60 × 6	5.50	5.64	—
	60 × 60 × 8	7.13	7.29	—
	70 × 70 × 8	9.70	9.90	—
	80 × 80 × 8	12.68	12.92	—
Detail B curb angle	60 × 60 × 6	23.35	24.35	—
	70 × 70 × 6	31.88	33.24	—
	80 × 80 × 6	41.63	43.43	—
	90 × 90 × 6	52.69	54.98	—
	90 × 90 × 8	56.86	67.74	—
	100 × 100 × 8	65.80	82.41	—
Detail C single angle	60 × 60 × 6	24.26	25.19	—
	60 × 60 × 8	29.70	31.06	—
	100 × 75 × 8	68.10	71.31	—
	100 × 75 × 10	79.26	83.43	—
	125 × 75 × 8	90.84	95.29	—
	125 × 75 × 10	106.38	112.07	—
	150 × 75 × 10	135.72	143.10	—
	150 × 90 × 10	153.09	161.45	—
Detail D channel	178 × 76 (20.84 kg/m)	172.50	176.62	—
	203 × 76 (23.82 kg/m)	219.65	224.99	—
	229 × 76 (26.06 kg/m)	261.88	268.65	—
	254 × 76 (28.29 kg/m)	305.62	313.94	—
	254 × 89 (35.74 kg/m)	393.23	402.60	—
	305 × 89 (41.69 kg/m)	521.30	534.61	—
	305 × 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 = 1 000	—	2173.58	2421.24

Dimensions are in millimetres, unless otherwise stated.

[a] Mass per unit length given in parentheses, where appropriate.

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[a]
m	mm
$D \leq 20$	100 × 65 × 8
$20 < D \leq 36$	125 × 75 × 8
$36 < D \leq 48$	150 × 90 × 10
$48 < D$	200 × 100 × 12

[a] 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.

a) 5 mbar, for open-top tanks irrespective of the design wind speed.

b) 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.

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

$$H_E = \Sigma H_e$$

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

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

where

- D is the tank diameter (in m);
- t_{min} is the thickness of the top course (in mm);
- t is the thickness of each course in turn (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	t	H_e
	m	mm	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 × 100 mm × 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	t	H_e
	m	mm	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 × 90 mm × 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);

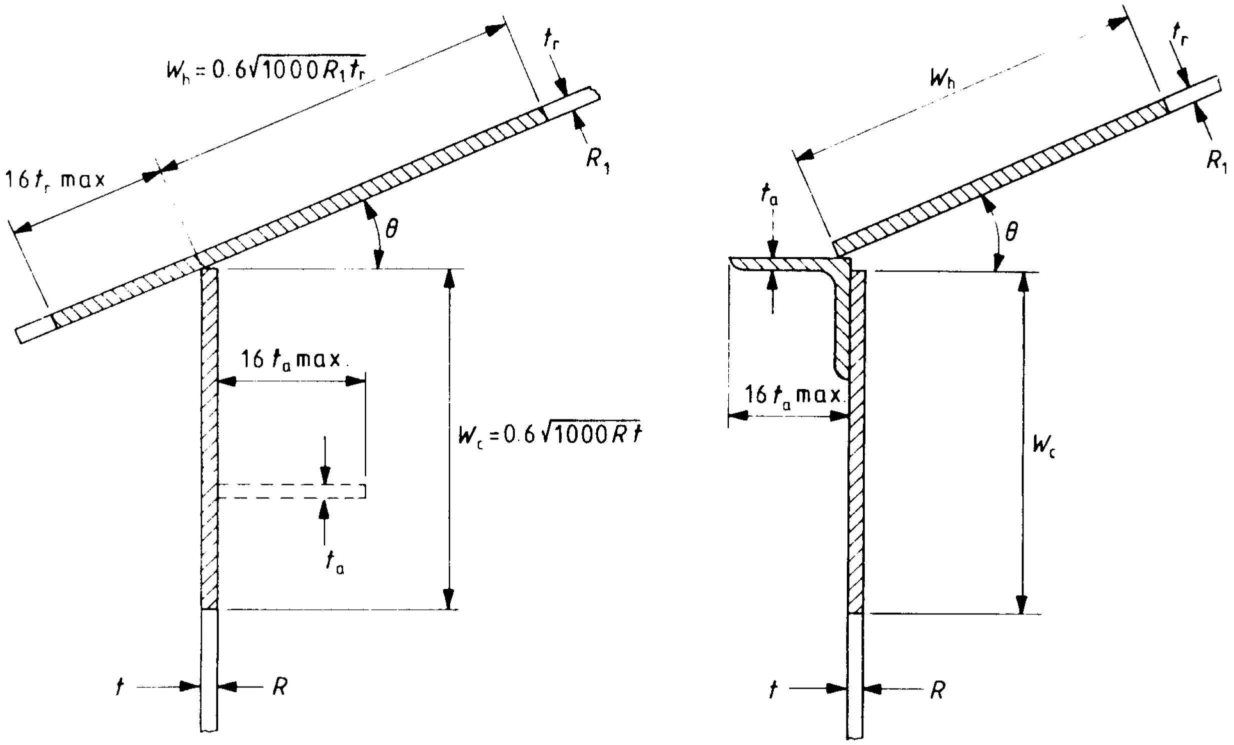
S is the allowable design stress (in N/mm^2);

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.



Key to symbols

R_1 is the radius of curvature of roof (in m) (for conical roofs = $R/\sin\theta$);
R is the radius of tank shell (in m);
t is the thickness of shell (in mm);
t_a is the thickness of angle stiffener (in mm);
t_r is the thickness of roof plate at compression ring (in mm);
W_h is the effective roof length (in mm).

Figure 7 — Shell-roof compression areas (see **8.5.1**)

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 size 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 overpressure 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 windskirt 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/m^2 (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 × 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/m^2. 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 hose 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.

10.4 Holding-down bolt or strap

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

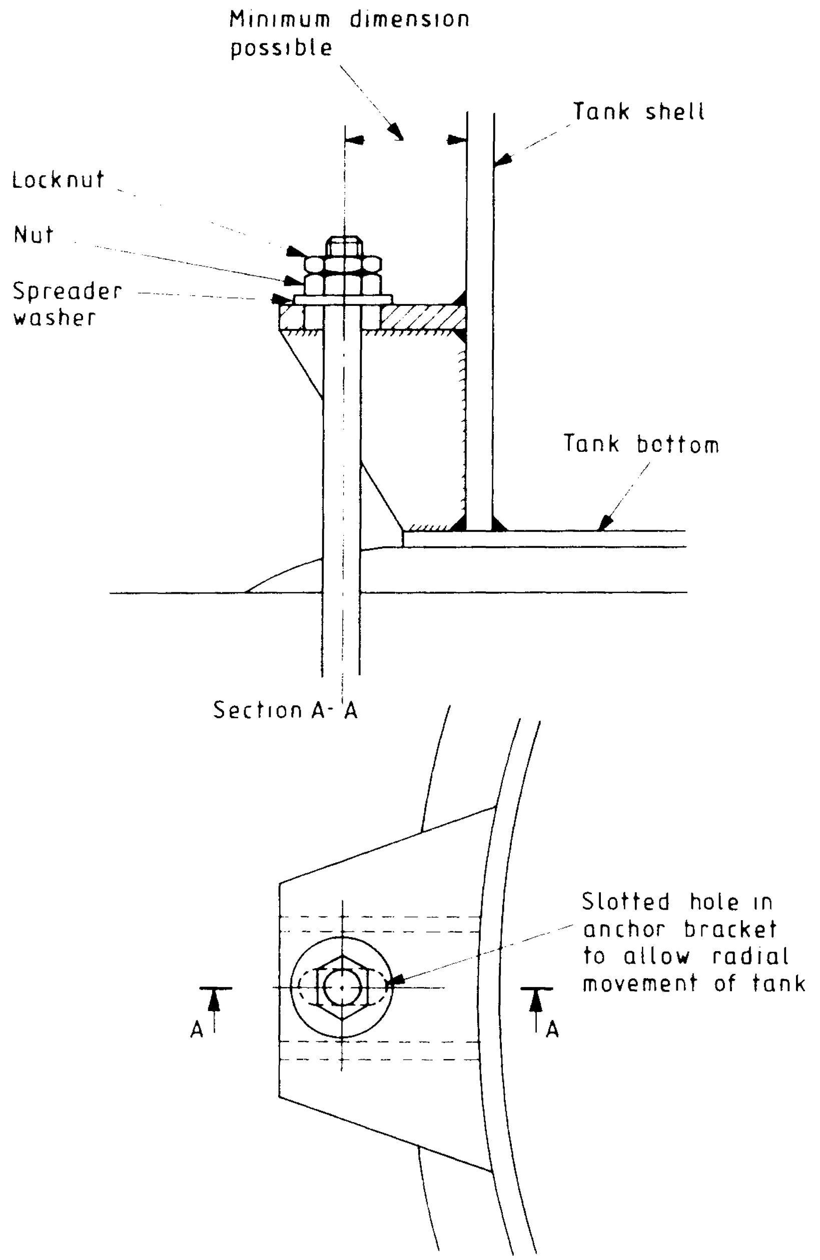


Figure 8 — Typical tank anchorage detail (see **10.2**)

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.

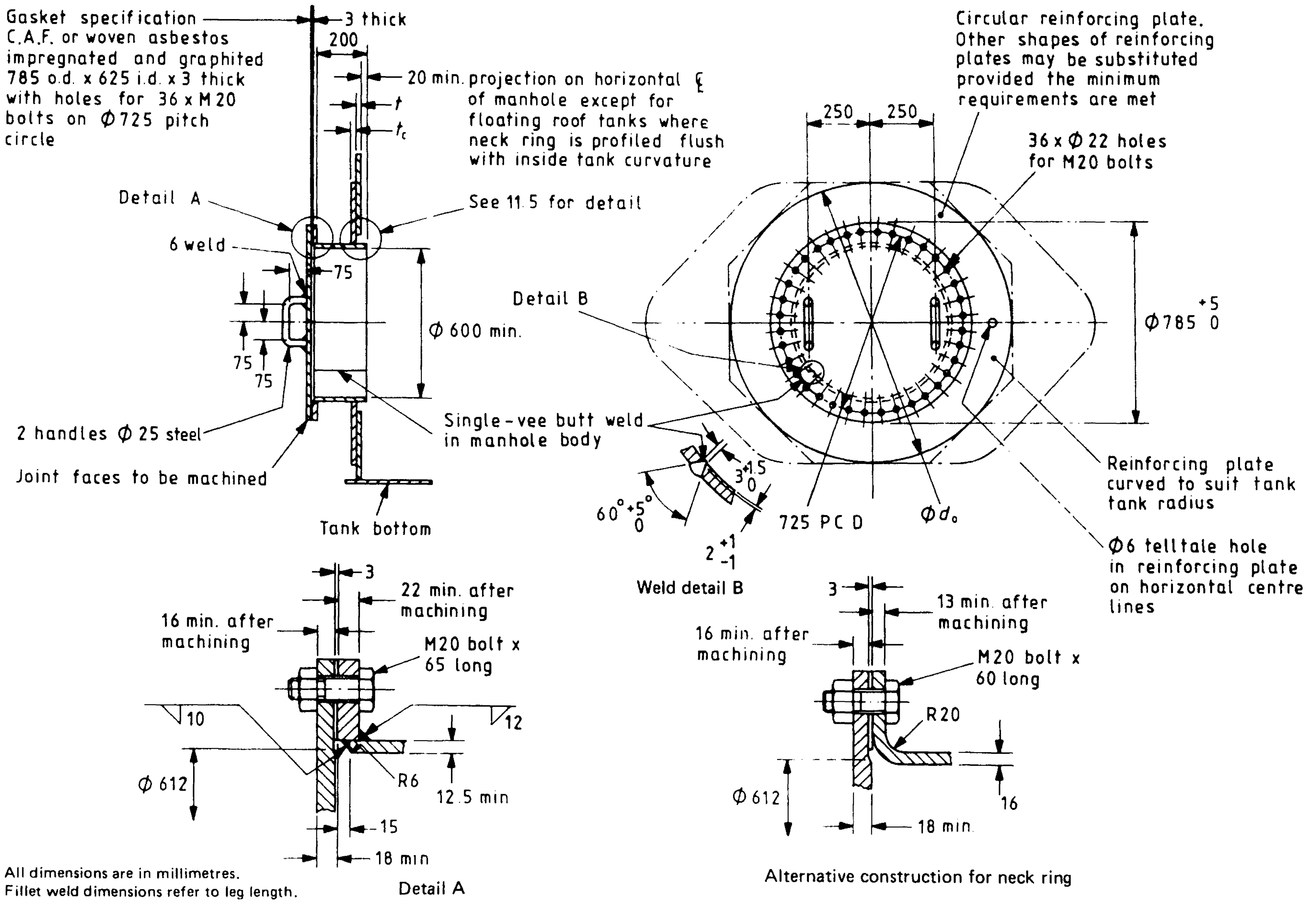
b) The provision of a thickened nozzle or manhole body. The portion of the body which may be considered as reinforcement is that lying within the shell plate thickness and within a distance of four times the body thickness from the shell plate surface unless the body thickness is reduced within this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



All dimensions are in millimetres.
Fillet weld dimensions refer to leg length.

NOTE. Attention is drawn to the regulations covering the use of asbestos.

Figure 9 — Shell manholes (see **11.1**)

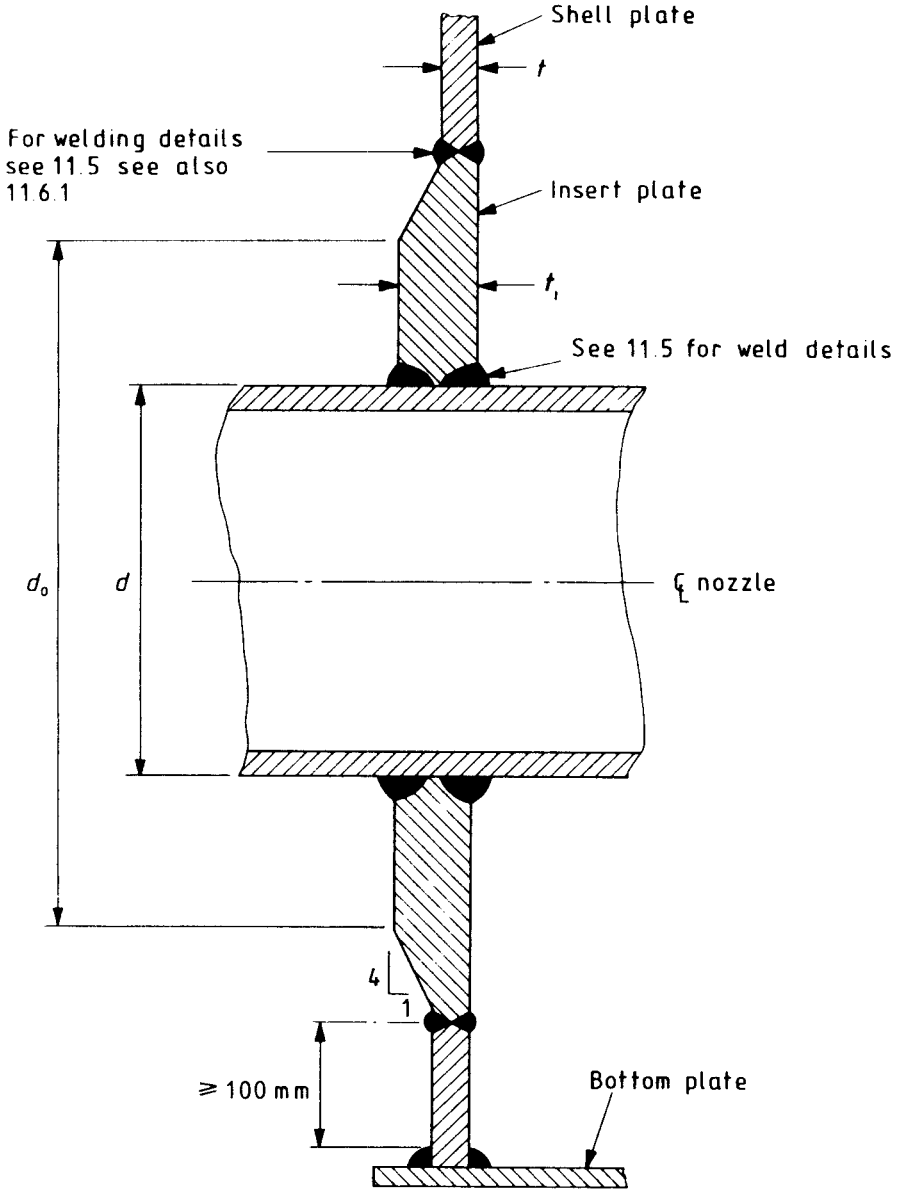
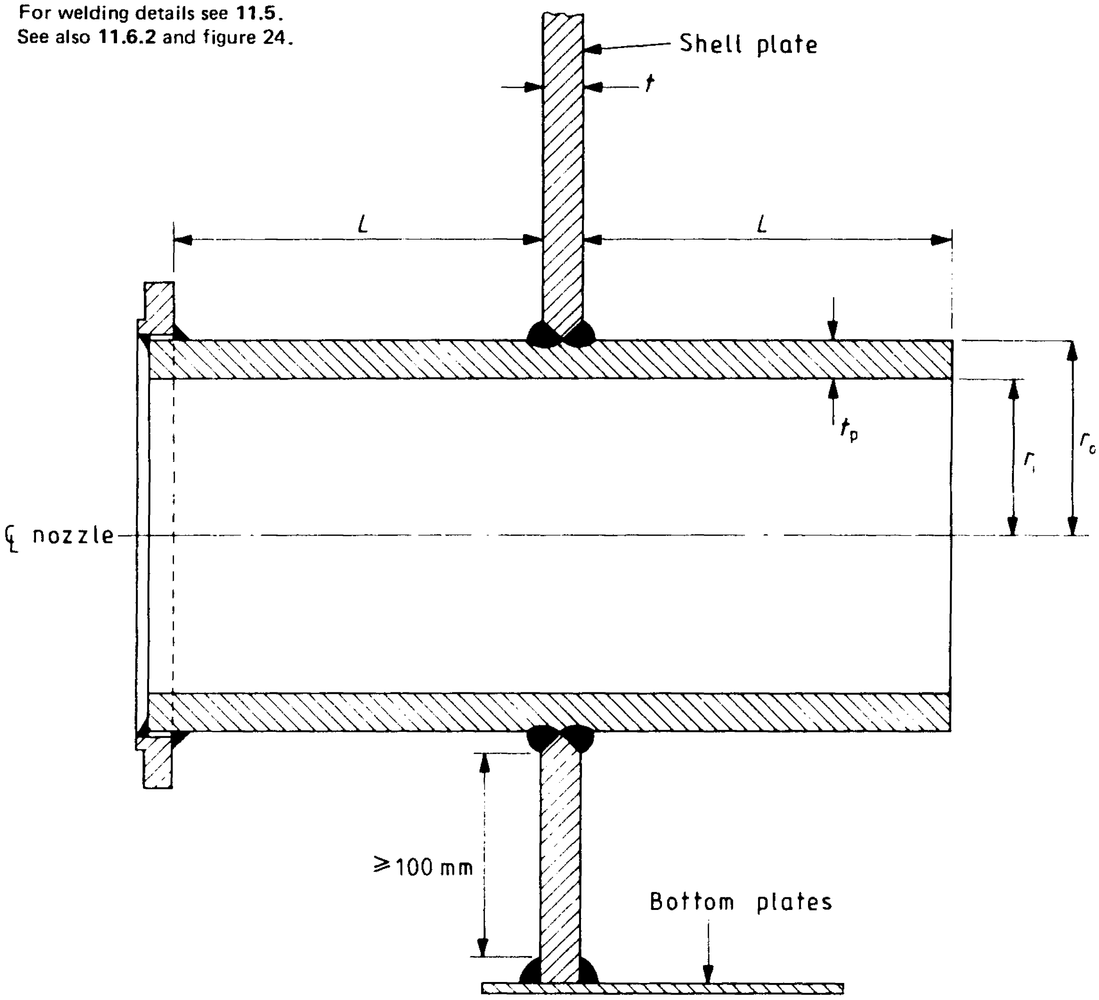


Figure 10 — Shell insert type reinforcement (see **11.1.2.2**)

For welding details see **11.5**.
See also **11.6.2** and figure 24.

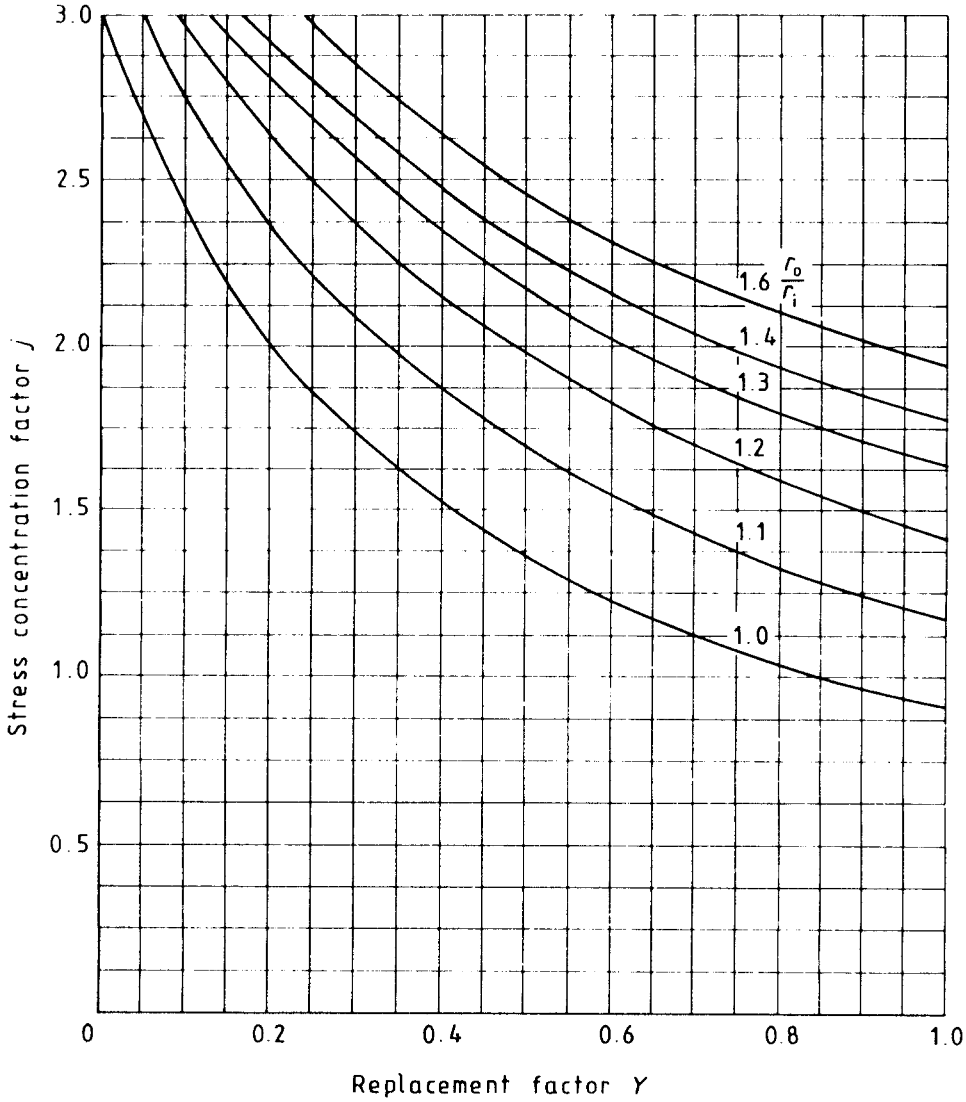


$L \geq 1.17\sqrt{r_m t_p}$

where

$r_m = \frac{r_o + r_i}{2}$

Figure 11 — Barrel type nozzle reinforcement (see **11.1.2.3**)



$$y = 1.56\sqrt{\frac{t_p^3}{r_m t^2}} + \frac{t_p}{2r_m}$$

where

t is the shell plate thickness (in mm);

t_p is the nozzle body thickness (in mm);

r_m is the mean radii for branch bodies (in mm).

All dimensions are in millimetres.

Figure 12 — Graph for the determination of the thickness of barrel type nozzle reinforcement (see **11.1.2.3**)

(Rose R.T. Rim Reinforcement of Manholes. *British Welding Journal,* October 1961.)

11.2 Shell nozzles less than 80 mm o.d.

Set-on nozzles shall not be permitted in sizes of 80 mm o.d. and above. No additional reinforcement shall be required for nozzles less than 80 mm o.d., provided that the thickness of the body is not less than that given in Table 5.

NOTE Set-on nozzles (see Figure 21) 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-particle crack detection is recommended.

11.3 Roof manholes and nozzles

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

The manhole covers shall be either as specified by the purchaser [see **3.2** g)] or of the multiple-bolt fixed or hinged type.

Flanged nozzles for fixed-roof tanks shall be as shown in Figure 13.

11.4 Additional loads

Nozzles shall be designed to withstand the loads specified in **5.5**.

11.5 Nozzle welding details

NOTE 1 Typical weld details for nozzles, manholes and other openings are shown in Figure 14 to Figure 21 and recognized weld details for connection of mountings are shown in Figure 22.

NOTE 2 Other forms of joint preparation are permitted by agreement between the manufacturer and the purchaser.

11.5.1 The partial penetration welds, e.g. as shown in Figure 18 and Figure 20(e) and Figure 20(f), shall only be used when the shell thickness (t) is not more than 12.5 mm and the allowable design stress (S) is less than 185 N/mm^2.

11.5.2 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 100 mm to the centre line of any other shell butt joint, the toe of the shell to bottom fillet weld, or the toe of fillet welds of adjacent attachments.

NOTE The reinforcing plate or insert plate may be extended to the shell to bottom junction provided the plate intersects the bottom at 90° (see Figure 23).

11.5.3 The dimensions of the welds connecting set-through nozzles to the shell are not required to be larger than twice the wall thickness of the mounting (for examples see Figure 14 to Figure 20).

When the thickness of nozzle bodies manufactured from rolled plate exceeds 20 mm, either material with specified through-thickness properties shall be used or a minimum layer of 3 mm of weld metal shall be applied to the surface of the body, prior to welding the nozzle to the shell (see Figure 24).

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

11.5.5 The leg length of fillet welds around the periphery of reinforcing plates shall equal the thickness of the reinforcing plate or 20 mm, whichever is less.

11.6 inspection of shell manholes and nozzles

11.6.1 The butt weld connecting insert plates to the shell plate shall be fully radiographed (see **17.3.2**) in accordance with **17.4**.

11.6.2 Longitudinal and circumferential butt welds in nozzles shall be 100 % visually examined to ensure complete fusion, i.e. in single-sided welds, the inside shall be examined to ensure adequate penetration and in double-sided welds, the back gouge shall be examined to ensure removal of the root face.

On completion, dye-penetrant crack detection shall be carried out where accessible.

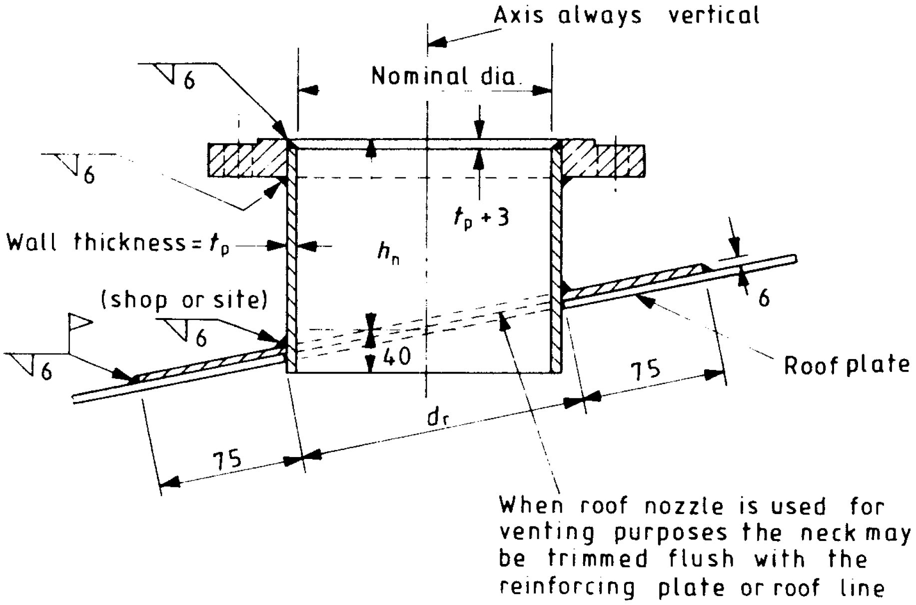
11.6.3 All other welds shall be fully magnetic-particle crack detected before the hydrostatic test or, where applicable, before and after post-weld heat treatment. The weld surface shall be such as to ensure that interpretation of the crack detection is not impaired.

11.6.4 When the thickness of nozzle bodies manufactured from rolled plate exceeds 20 mm, that area of the body to be welded to the shell shall be ultrasonically examined to ensure freedom from laminations.

11.7 Flange drilling

Unless otherwise specified by the purchaser [see **3.2** h)], the flanges of all mountings except shell and roof manholes shall be made and drilled in accordance with class 150 of BS 1560-2. The orientation of mating flanges shall be checked for compatibility.

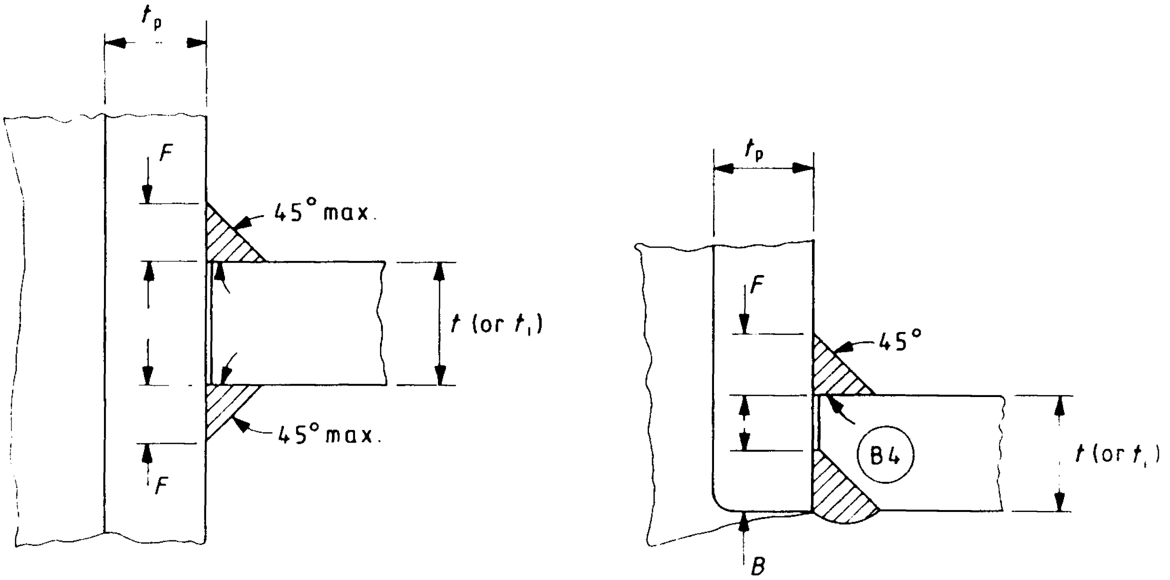
Dimensions of plate ring flanges to comply with class 150 of BS 1560 : Part 2 in all respects, except that extended hub at back of flange may be omitted. Slip-on flanges complying with class 150 of BS 1560 : Part 2 (forged steel) may be substituted for plate ring flanges.



Nominal diameter of nozzle		Outside diameter of pipe	Diameter of hole in roof plate d_r	Height of nozzle h_n	Nominal pipe wall thickness t_p
in	mm	mm	mm	mm	mm
1	25	34	40	150	3.4
2	50	60	66	150	3.9
3	80	89	95	150	5.5
4	100	114	120	150	6.0
6	150	168	174	150	7.1
8	200	219	230	150	8.2
10	250	273	284	200	9.3
12	300	324	336	200	9.5

All dimensions are millimeters.
Fillet weld sizes refer to leg lengths.

Figure 13 — Flanged roof nozzles (see **11.3**)

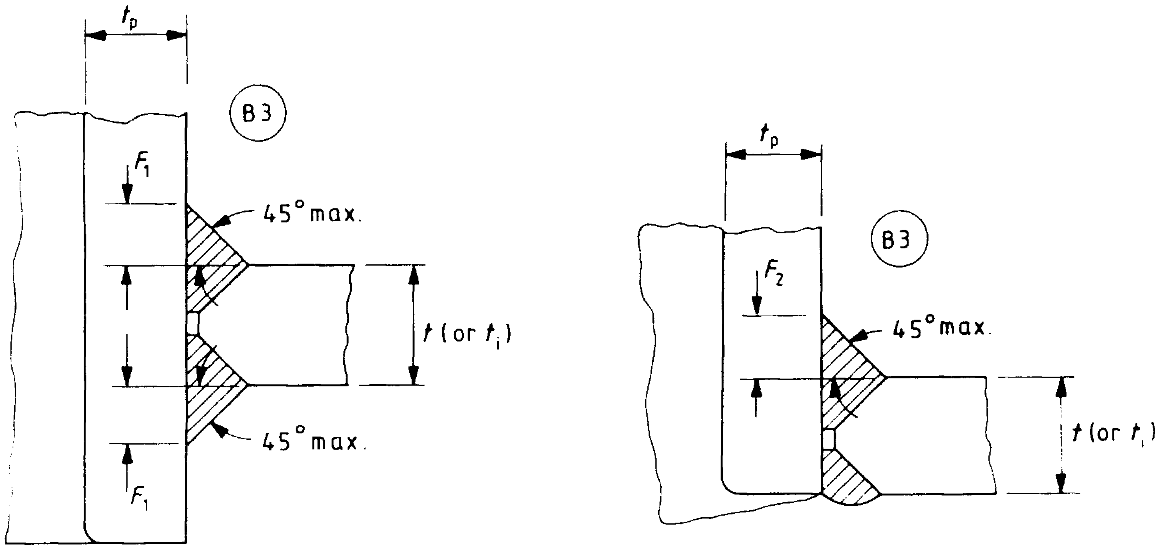


(a) (b)

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

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

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

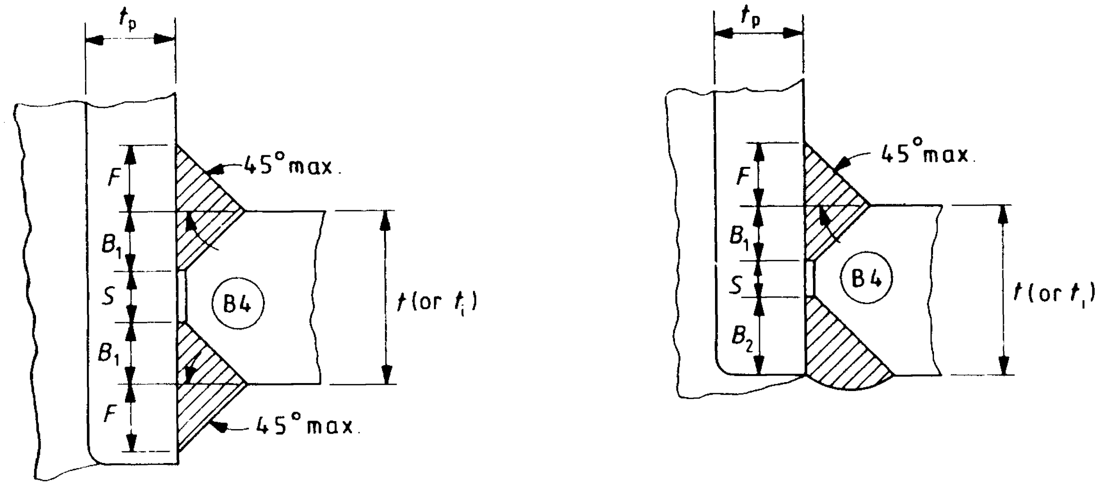


(c) (d)

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

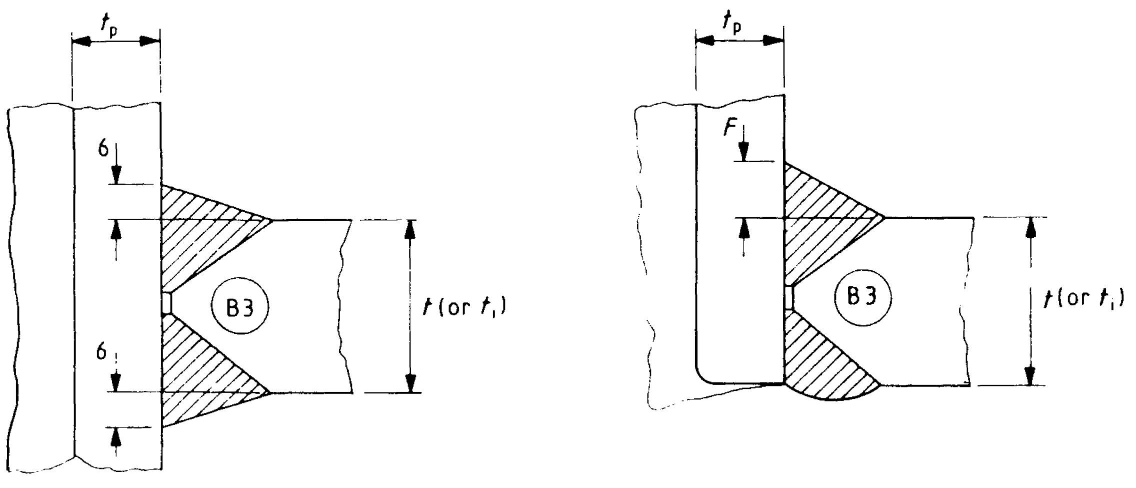
All dimensions are in millimetres.

Figure 14 — Typical weld details for connection of mountings: set-through type (preferred details): *t* = 20 mm (max.) (See Figure 22 for recognized weld details.)



(a) (b)

F = 6 min., 13 max.
$B_1 + F = t_p$, $B_2 = t_p$. If B_1 or B_2 exceeds 16, use J-type weld detail.
If S is less than 3, use details c and d as appropriate.
t_p = 12.5 max.

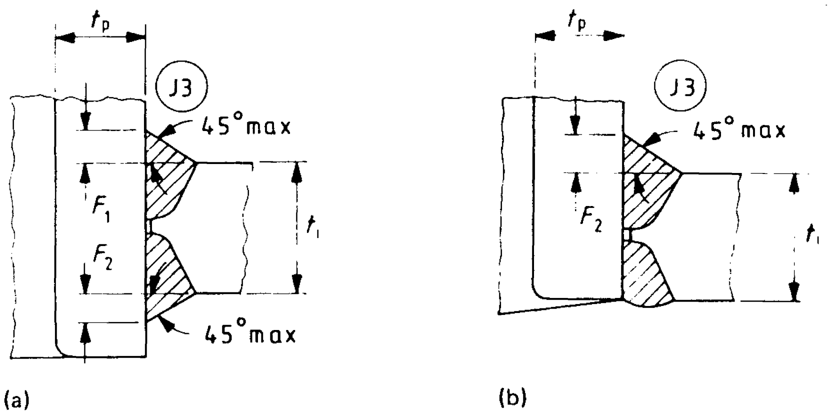


(c) (d)

$F = t/4$, but not less than 6.
If t exceeds 30, use J3 weld detail.
t_p exceeds 12.5

All dimensions are in millimetres.

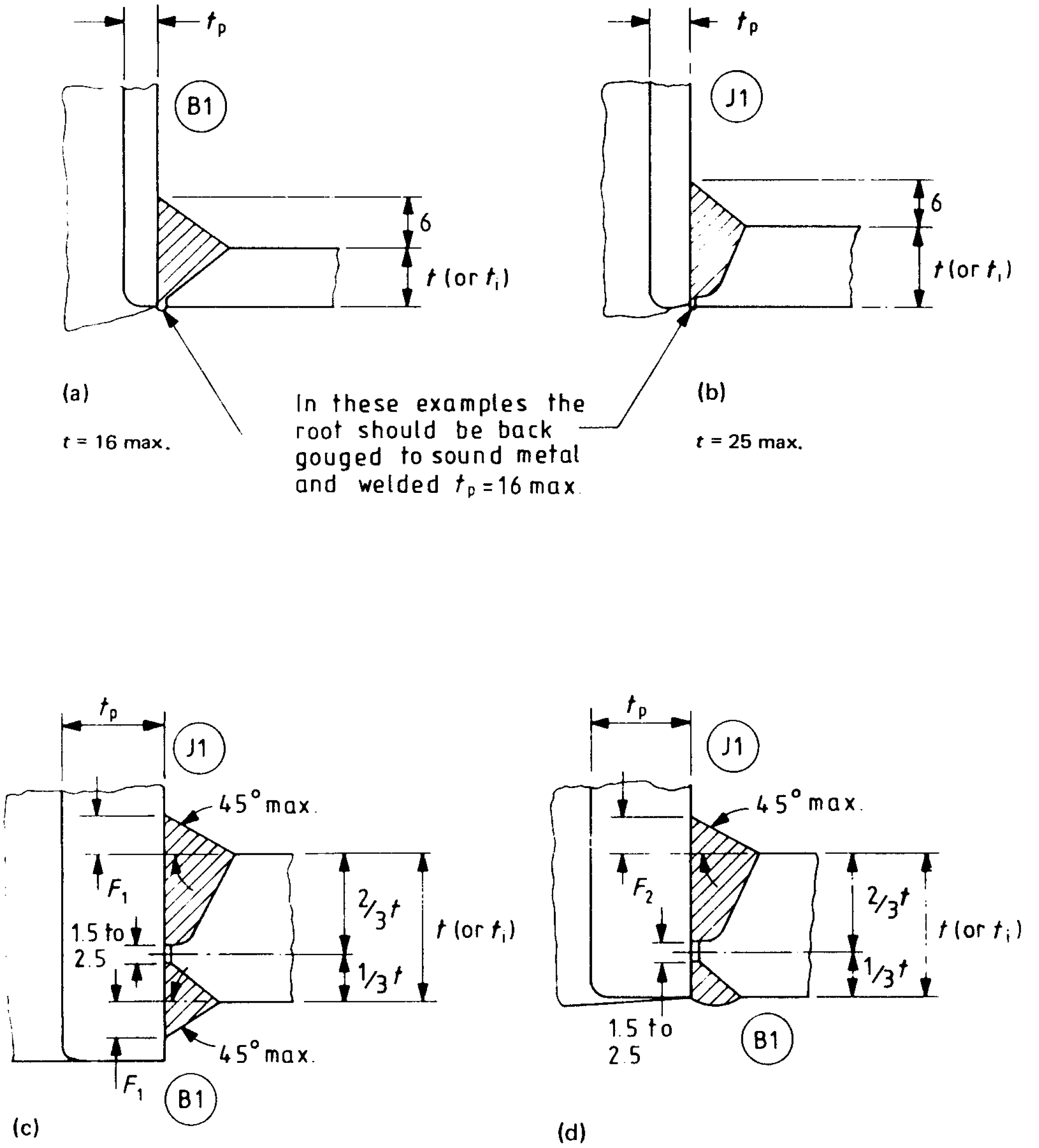
Figure 15 — Typical weld details for connection of mountings: set-through type (preferred details): 20 mm ≤ *t* ≤ 40 mm (See Figure 22 for recognized weld details.)



F_1 = t_i/8 min., but not less than 6.
F_2 = t_i/4 min., but not less than 13.

All dimensions are in millimetres.

Figure 16 — Typical weld details for connection of mountings: set-through type (preferred details): t_i 40 mm (See Figure 22 for recognized weld details.)



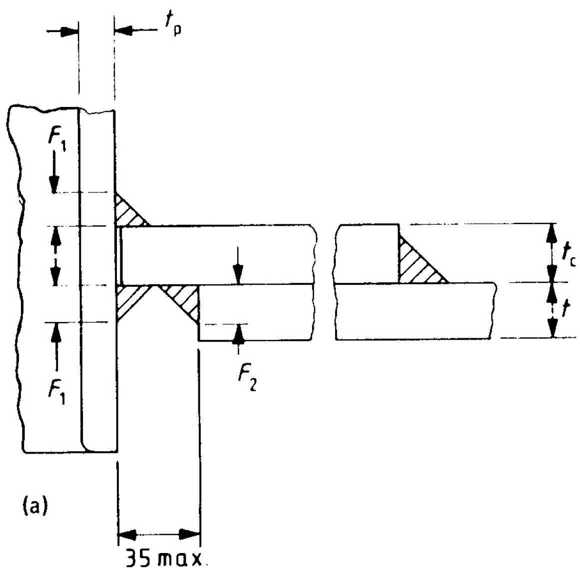
F_1 = t/8, but not less than 6.

F_2 = t/4, but not less than 6 and not more than 13.

t exceeds 20, t_p exceeds 12.5. If t_i exceeds 50, use J1 weld detail both sides.

All dimensions are in millimetres.

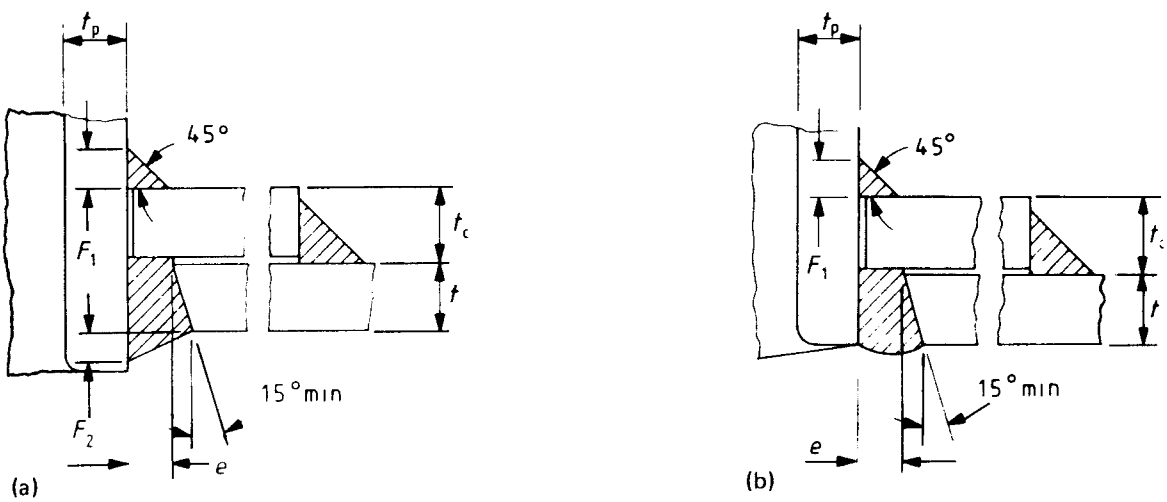
Figure 17 — Typical weld details for connection of mountings: set-through type (alternative details) (See Figure 22 for recognized weld details.)



F_1 = lesser of t_p and t_c, with a minimum of 6.
F_2 = t, with a maximum of 10.
See **11.5.1** for restrictions on the use of this detail.

All dimensions are in millimetres.

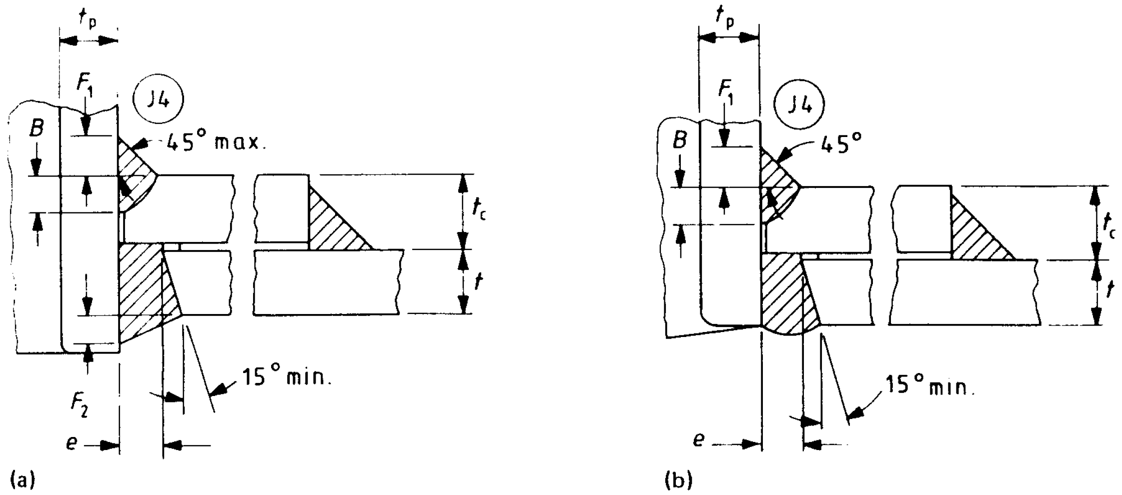
Figure 18 — Typical weld details for connection of mountings: compensated set-through type (preferred details): t = 12.5 mm (max.)



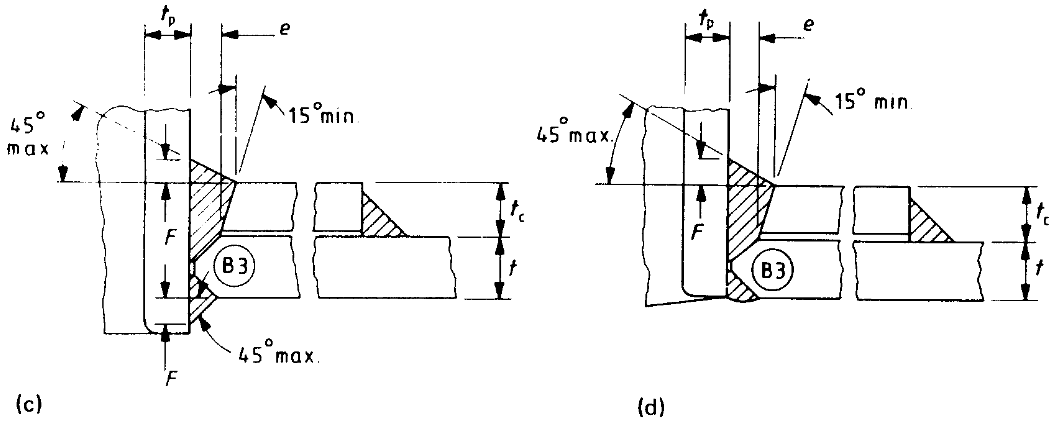
F_1 = lesser of t_p and t_c, with a minimum of 6.
e = 10 min. to 20 max. as required for access.
F_2 = t_p/3 min. but not less than 6.

All dimensions are in millimetres.

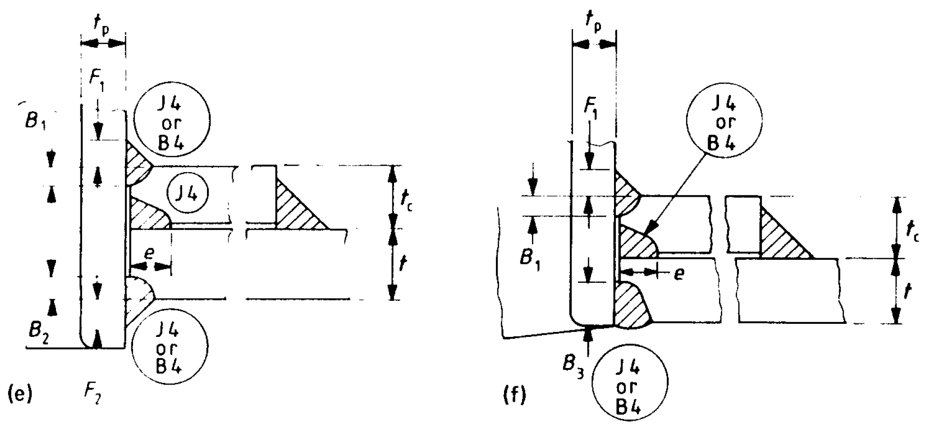
Figure 19 — Typical weld details for connection of mountings: compensated set-through type (preferred details)



$B + F_1$ = lesser of t_p and t_c.
F_1 = 6 min.
e = 10 min. to 20 max. as required for access.
F_2 = t_p/3 min. but not less than 6.



F = t_p/3 min. but not less than 6.
e = 10 min. to 20 max. as required for access.

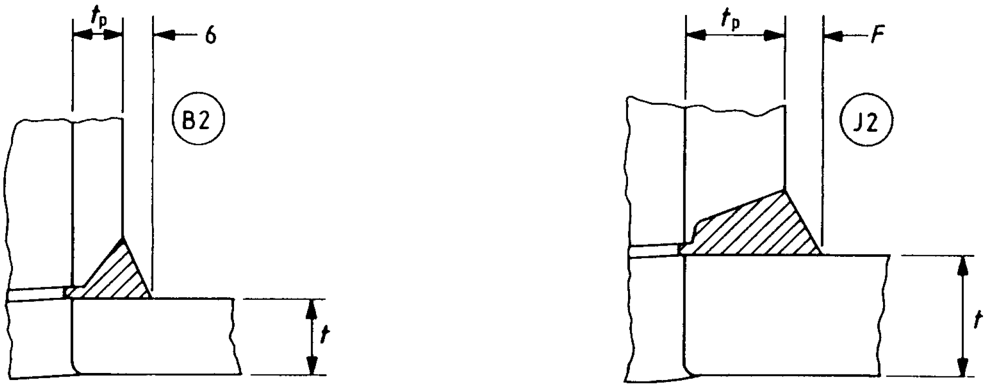


t = 12.5 max.
$(B_1 + F_1) = e$ = lesser of t_p and t_c, with a minimum of 6.
$(B_2 + F_2)$ or B_3 = lesser of t_p and t, with a minimum of 6.
See **11.5.1** for restrictions on the use of details (e) and (f).

All dimensions are in millimetres.

Figure 20 — Typical weld details for connection of mountings: compensated set-through type (alternative details) (See Figure 22 for recognized weld details.)

Set-on nozzles: attention is drawn to the necessity to examine the shell plate for laminations around the branch hole when set-on nozzles are used (see **11.2**).



(a)

t_p = 16 max.

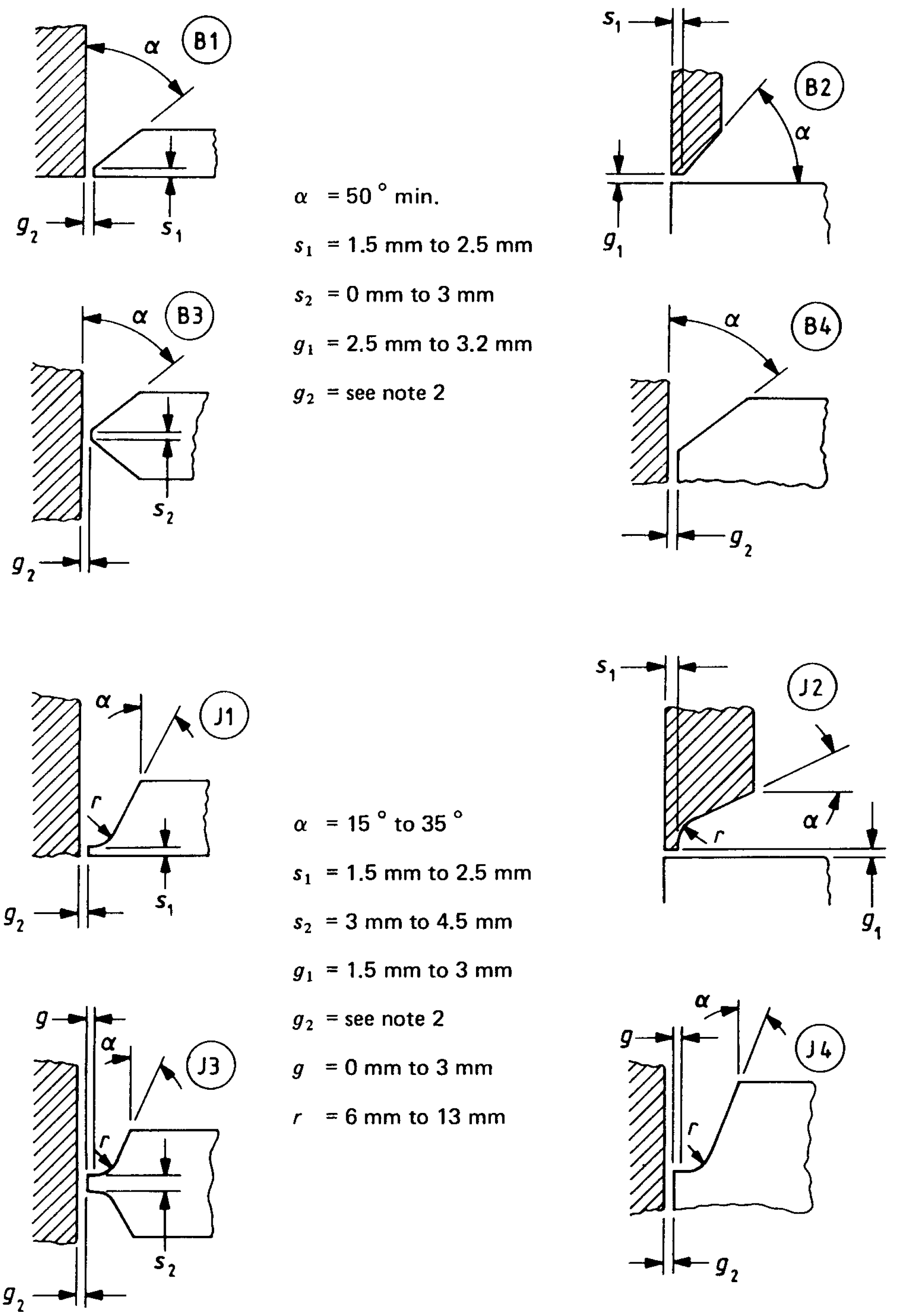
(b)

$t_p > 16$
$F = t_p/3$

If the welding procedure does not ensure sound positive root penetration, these joints should be back chipped or gouged and back welded. The internal penetration bead of joints welded from one side only are to be ground smooth and flush with the inside bore.

All dimensions are in millimetres.

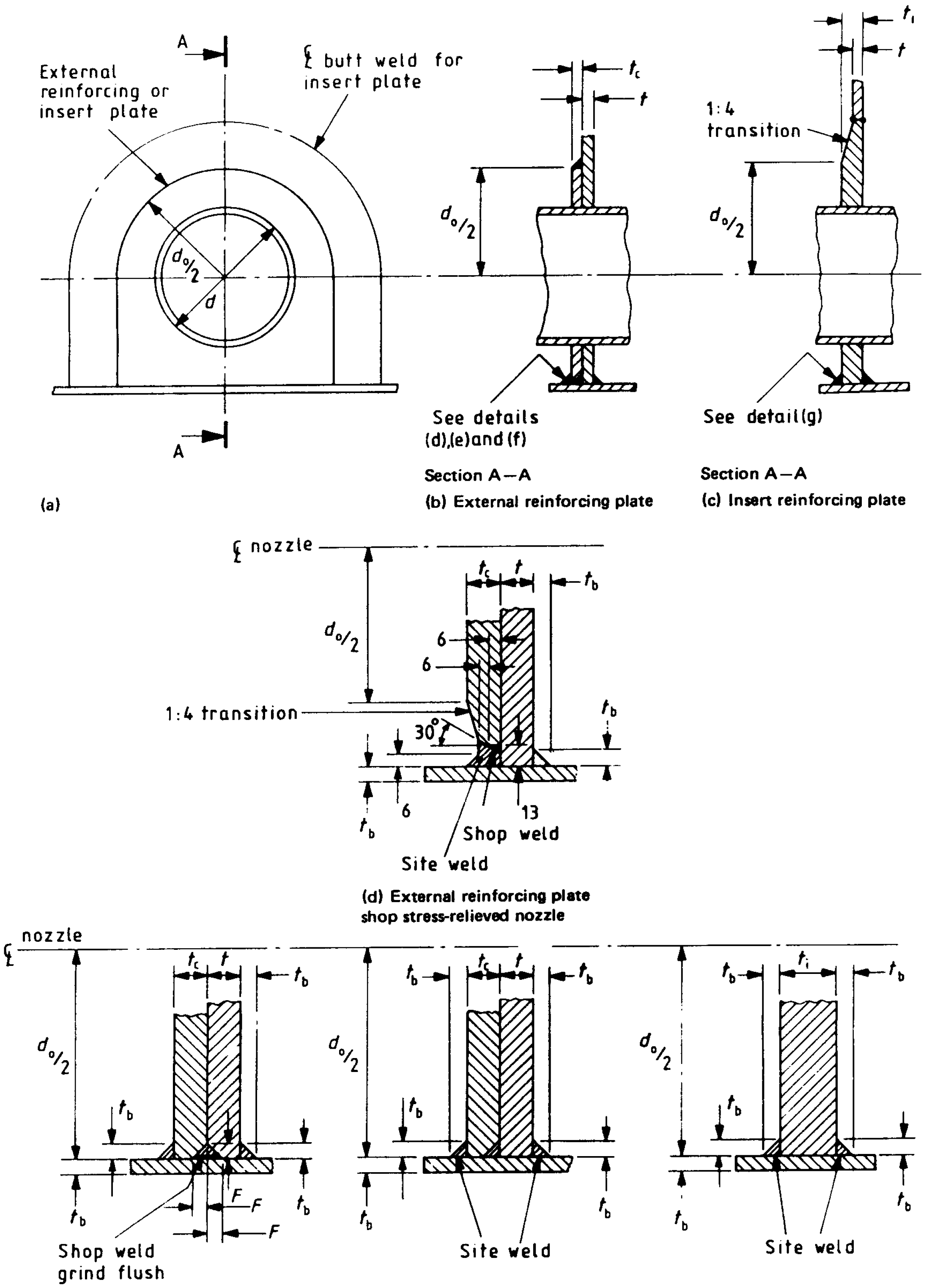
Figure 21 — Typical weld details for connection of mountings: set-on type (shell nozzles less than 80 mm o.d.) (See Figure 22 for recognized weld details.)



NOTE 1 These recommendations have been included for general guidance. Discretion has to be used in applying the maximum and the minimum dimensions quoted which are subject to variation according to the welding procedure employed, e.g. size and type of electrodes, as well as position in which the welding is carried out and the welding process adopted.

NOTE 2 It is recommended that is no case should the gap between nozzle and adjacent plate exceed 3 mm. Wider gaps increase the tendency to spontaneous cracking during welding, particularly as the thickness of the parts joined increases.

Figure 22 — Recognized weld details for connection of mountings



(a)

(b) External reinforcing plate

(c) Insert reinforcing plate

(d) External reinforcing plate shop stress-relieved nozzle

F = lesser $t_b/2$ and $t_c/2$.

(e) External reinforcing plate shop stress-relieved nozzle

(f) External reinforcing plate non-stress-relieved nozzle

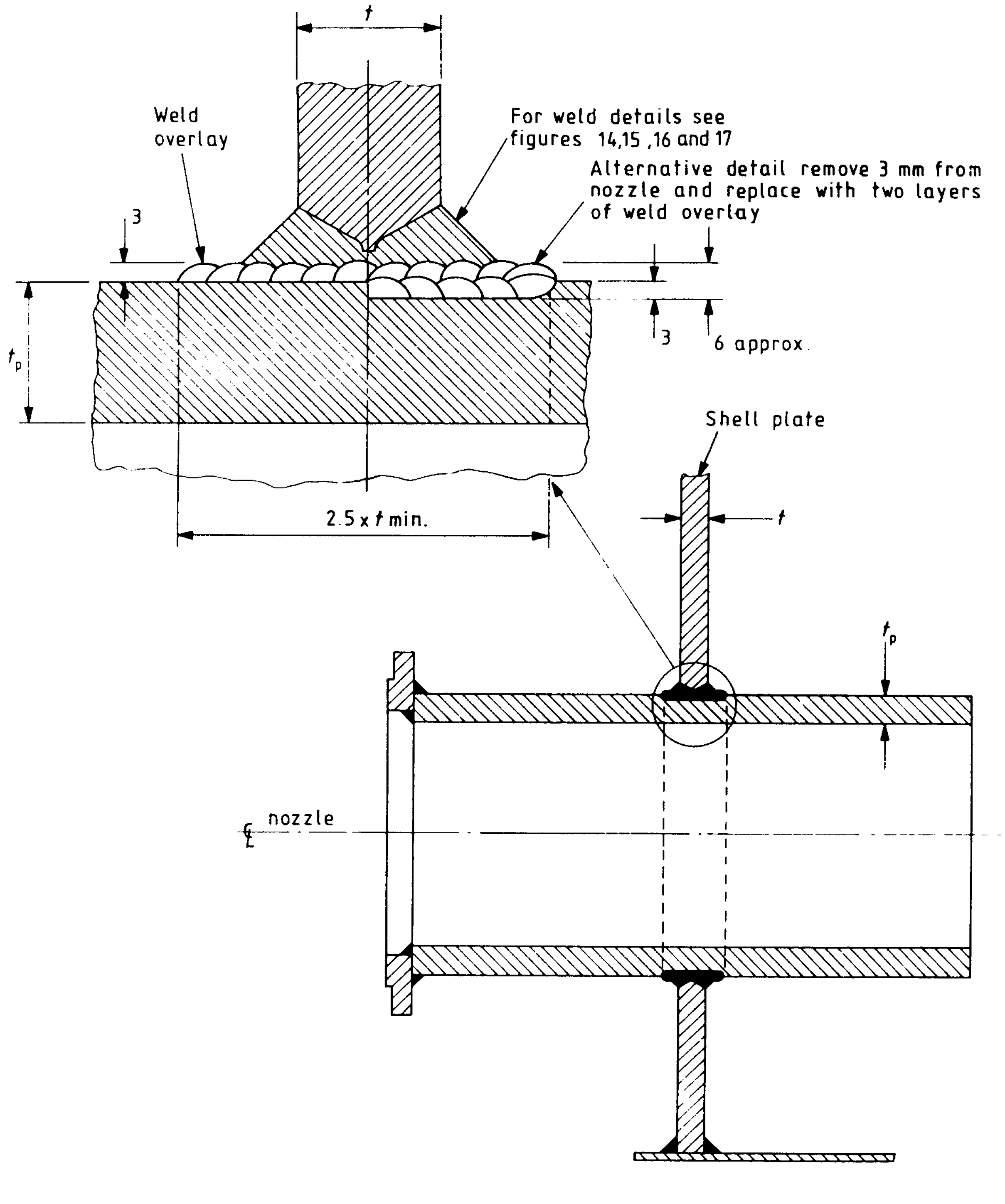
(g) Insert reinforcing plate. Stress-relieved or non-stress-relieved nozzles

Key to symbols

t is the shell plate thickness
t_i is the insert plate thickness
t_c is the reinforcing plate thickness
t_b is the bottom plate thickness

All dimensions are in millimetres.

Figure 23 — Reinforcement details for low type nozzles



All dimensions are in millimetres.

Figure 24 — Details of overlay weld for nozzles (see **11.5.3**)

11.8 Post-weld heat treatment

11.8.1 If mountings involving openings 300 mm or larger are welded to shell plates thicker than 20 mm, all lap or fillet welds connecting the barrel or compensating plate to the shell and all butt welds incorporating plates thicker than 40 mm at the prepared edges shall be post-weld heat treated in accordance with **11.9**.

11.8.2 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 be not less than its width.

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

11.8.4 Subsequent welds to nozzles shall not be closer to any weld which has been post-weld heat treated than:

$$2.5\sqrt{r_i t_p}$$

where

r_i is the inside radius of the pipe (in mm);

t_p is the wall thickness (in mm).

11.9 Procedure for post-weld heat treatment

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

11.9.2 The rate of heating above 400 °C (in °C per hour) shall not exceed the following, with a maximum rate of 200 °C per hour:

$$\frac{5000}{(t \text{ or } t_i)}$$

where

t is the shell plate thickness (in mm);

t_i is the bottom course plate thickness (in mm).

11.9.3 During the heating period there shall not be a greater variation in temperature thoughout the assembly being heated than 150 °C within any 5 m interval of length and when at the holding temperature, the temperature throughout shall be within the range 580 °C to 620 °C.

11.9.4 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.

11.9.5 When the assembly has attained a uniform temperature as specified in **11.9.3**, the temperature shall be held constant for a period in hours equal to 4 % of the thickness in millimetres of the shell plate, with a minimum of one hour.

11.9.6 The assembly shall be cooled in the furnace to 400 °C at a rate in °C per hour not exceeding the following, with a maximum rate of 250 °C per hour:

$$\frac{6250}{(t \text{ or } t_i)}$$

where t and t_i are as defined in **11.9.2**.

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

11.9.7 The temperatures specified shall be actual temperatures of any part of the assembly and shall be determined by thermocouples attached to the assembly, unless it can be demonstrated that the type of furnace used will always comply with **11.9.1** to **11.9.7**.

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

11.10 Stairways and gangways

NOTE For stairways on insulated tanks, see **B.5.2**.

11.10.1 Local regulations shall be observed and any conflict with the requirements of this standard resolved.

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

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

11.10.3 The stairway treads shall be of the non-slip type.

NOTE The rise should normally be 200 mm with a minimum width of 200 mm measured at the mid-length of tread. The rise may be adjusted within ± 5 mm to make treads level with landings or platforms.

11.10.4 Spiral type stairways incorporating stair treads welded directly to the shell, or by means of local pads, shall only be permissible where:

a) the minimum specified tensile strength of the shell material does not exceed 460 N/mm^2; or

b) the minimum specified tensile strength of the shell material exceeds 460 N/mm^2 and the shell thickness does not exceed 12.5 mm.

Where the minimum specified tensile strength of the shell material exceeds 460 N/mm^2 and the shell thickness exceeds 12.5 mm, stairways shall be independently supported or affixed by horizontally oriented continuous welds (see **11.15**).

11.10.5 Stairways and gangways shall be capable of supporting a superimposed load of 2.4 kN/m^2 as well as the wind loadings specified for the design of the shell.

NOTE It is recommended that where the vertical rise of stairways is more than 6 m, intermediate landing or landings should be provided.

11.10.6 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.

11.11 Handrailing

11.11.1 Handrailing to tank roofs, stairways and gangways shall be of solid steel sections, and shall be designed to protect personnel and prevent objects from falling (see Figure 25 and Figure 26).

11.11.2 Handrails shall be provided on both sides of gangways and stairways, except on spiral stairways where the distance between the tank shell and the inner stringer is less than or equal to 200 mm when no inner handrail is required. At breaks in the handrail, the space, if any, between the tank and the platform shall be floored if the space exceeds 150 mm in width.

11.11.3 For tanks over 12.5 m diameter, where access is required to fittings at or near to the centre of the roof, handrailing and treads shall be provided.

11.11.4 Particular care shall be taken in the jointing of handrails to ensure that the full strength of the members is developed.

11.12 Ladders

Fixed steel ladders exceeding 4 m in height shall be provided with safety cages.

NOTE These should be generally in accordance with BS 4211.

11.13 Earthing connections

All tanks shall be fitted with suitable earthing connections.

NOTE A typical type of connection is shown in Figure 27.

11.14 Flush type clean-out doors, D-type sumps and water draw-off sumps

11.14.1 When it is proposed to embody flush type openings in the bottom course of shell plating, the vertical opening shall not exceed 915 mm or half the shell plate width, whichever is the lesser, for steels having a minimum specified tensile strength less than 460 N/mm^2 nor 300 mm for stronger steels. The assembly shall be prefabricated and stress relieved in accordance with **11.9**.

11.14.2 In view of the complicated stress pattern, the use of flush type openings shall be reduced to a minimum and typical details are shown in Figure 28 to Figure 31.

11.14.3 When it is proposed to use a combined water draw-off and clean-out sump the design shall be as shown in Figure 32. The fillet weld to the underside of the bottom sketch plate or annular plate shall be deposited in the flat position, the bottom plate being reversed for this purpose before final positioning on the tank foundation.

NOTE Types of acceptable draw-off sump are shown in Figure 33.

11.15 Permanent attachments

11.15.1 Permanent attachments welded to tank shells thicker than 12.5 mm shall be kept to a minimum and shall preferably be disposed in a horizontal direction.

NOTE 1 If vertical fillet welds are necessary, these should be made with special care, having due regard to their stress-intensifying effect.

NOTE 2 *Automatic level and temperature measuring instruments.* Where it is required to provide mountings to accommodate automatic level and temperature measuring instruments on tanks, attention is drawn to BS 3792.

11.15.2 Vertical attachment welds shall not be located within 150 mm of any main vertical seam and horizontal attachment welds shall not be made on top of any main horizontal seam. The soundness of fillet welds shall be checked by magnetic-particle crack detection to a sufficient extent to confirm the welding procedure which shall be agreed previously and designed to avoid any risk of underbead cracking (see **16.1.3**).

NOTE The use of multiple cleats or studs is not recommended.

Stud-welded and similar attachments shall not be permitted for plates exceeding 13 mm in thickness.

11.16 Temporary attachments

11.16.1 The requirements governing the location, orientation and procedure for the provision of temporary attachments other than the location of temporary key plate erection attachments shall be the same as for permanent attachments (see **11.15**).

11.16.2 When removing temporary attachments from shell plates, the attachment shall be burned 3 mm to 6 mm proud of the plate surface or, alternatively, the securing weld shall be weakened by chipping or gouging, taking care not to damage the parent plate, and the attachment shall be knocked off.

11.16.3 The resultant scar shall then be ground to a smooth profile, ensuring no underflushing of the plate surface occurs.

NOTE After grinding, the surface should be checked for cracks particularly on plates with specified minimum tensile strengths greater than 430 N/mm^2 and 20 mm thick and over. Should under-flushing be present, reference should be made to BS 4360 for guidance on possible repair.

12 Insulation

The permanent attachments associated with the requirements for the insulation of a storage tank [see **3.1** i)] shall comply with **11.15**.

NOTE Tanks designed to comply with this British Standard may require to be insulated for various reasons, e.g. maintaining product temperature. Although the design of this insulation is outside the scope of this standard, the recommendations of Appendix B should be taken into consideration in the design.

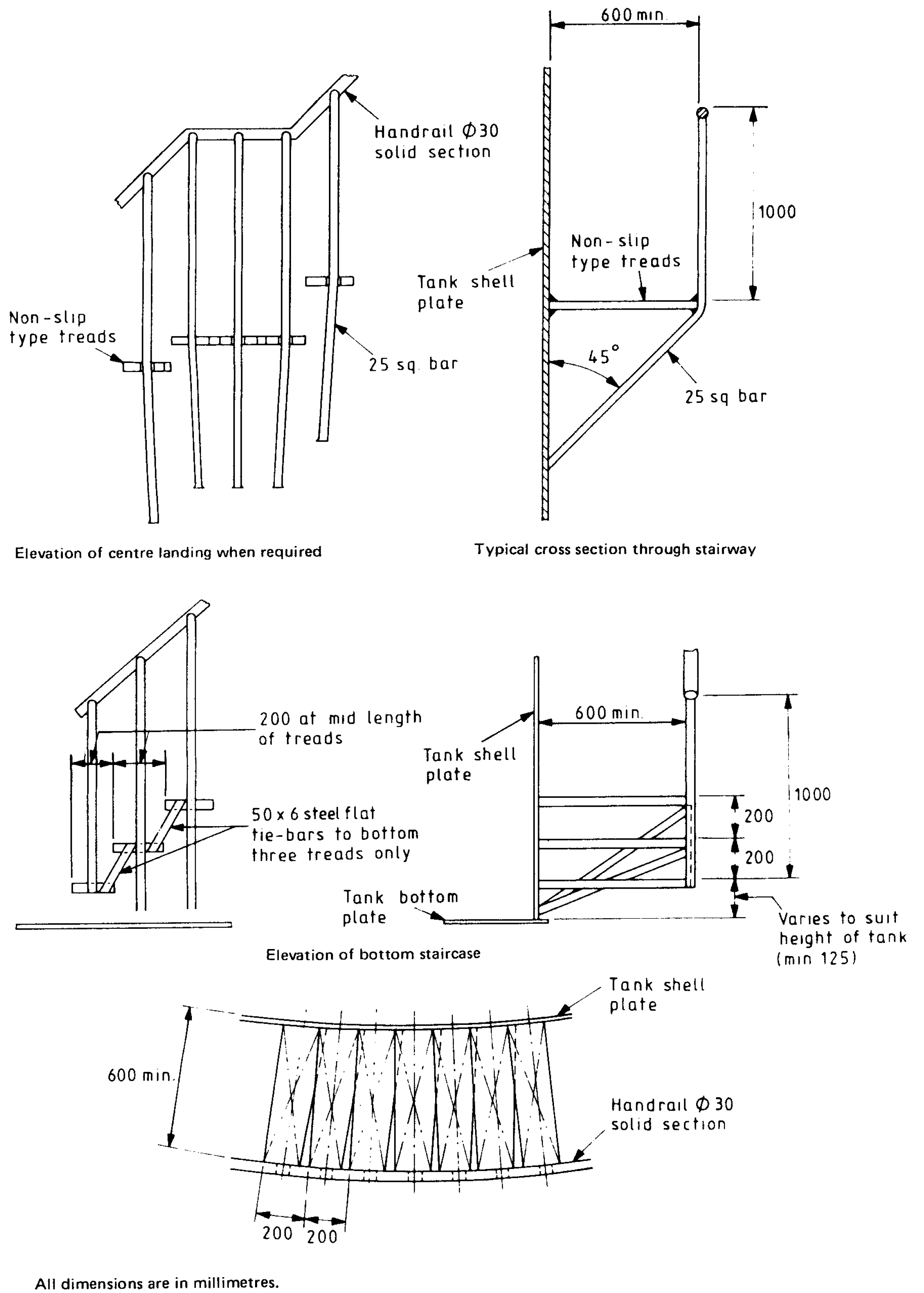


Figure 25 — Details of an acceptable type of spiral stairway (see **11.10** and **11.11**)

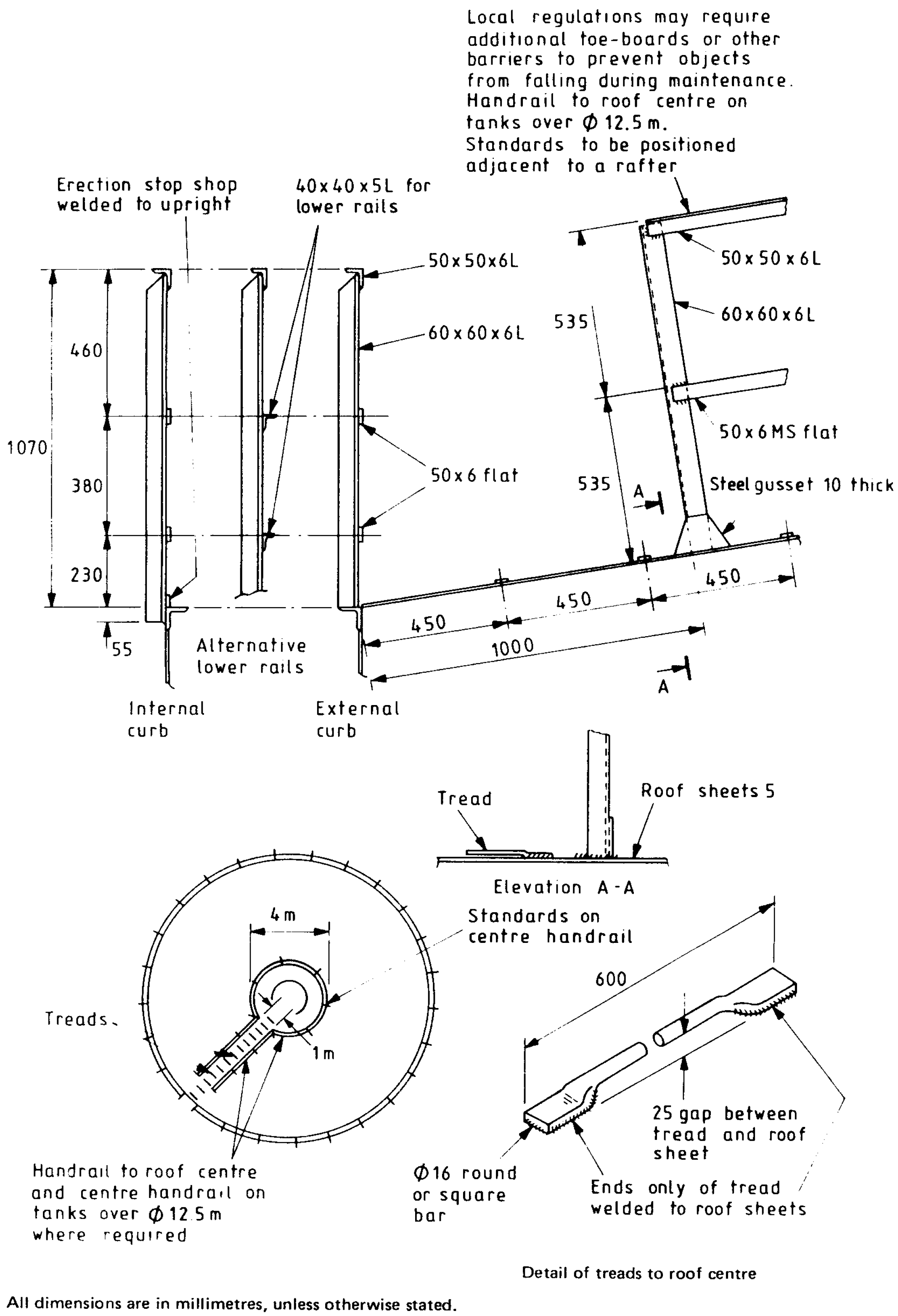
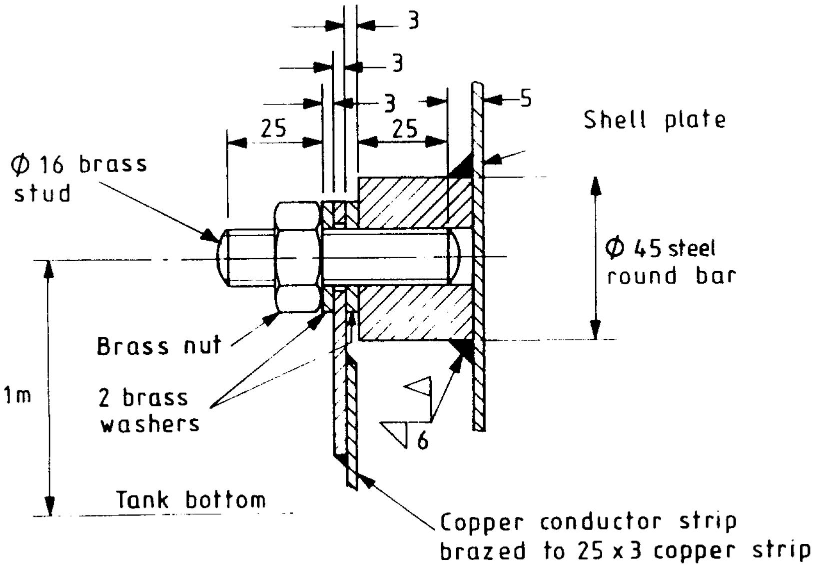
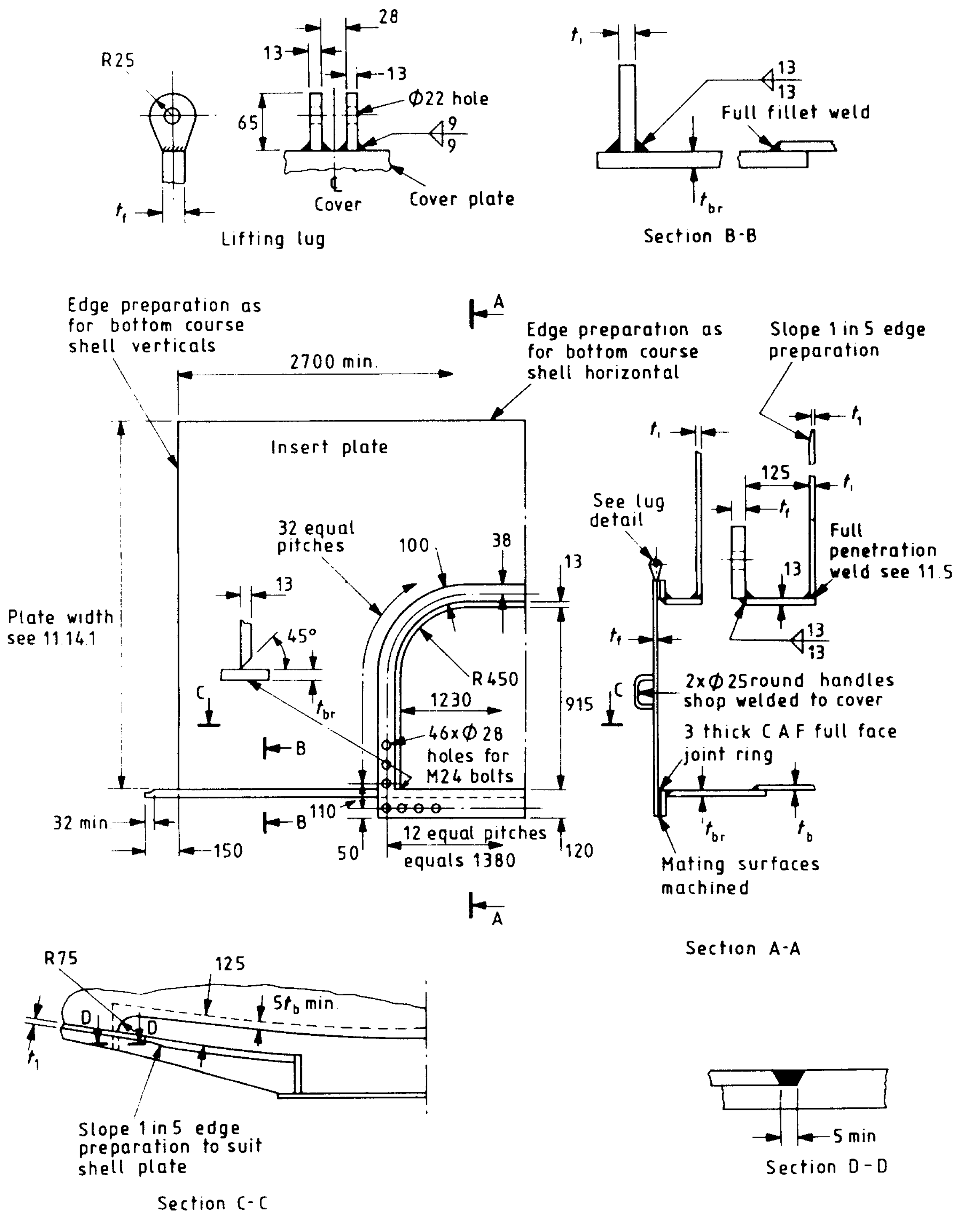


Figure 26 — Handrailing (see **11.11**)



All dimensions are in millimetres, unless otherwise stated.
Fillet weld dimensions refer to leg length.

Figure 27 — Typical detail of earthing boss (supplied with tank) site welded to tank shell plates (see **11.13**)



Key to symbols

t_1	is the bottom course shell thickness	$\leqslant$ 18.5 mm
t_i	is the thickness of 2.7 m insert plate	$= 2t_1 + 3 \leqslant 40$ mm
t_f	is the thickness of cover and flange	$= 0.78H + 11$
t_{br}	is the thickness of bottom reinforcing plate	$= 7\sqrt{H} + 3$
t_b	is the tank bottom plate thickness	
H	is the tank height (in m).	

All dimensions are in millimetres, unless otherwise stated.
Fillet weld dimensions refer to leg length.

(a) 915 mm × 1230 mm

Figure 28 — Flush type clean-out door with insert plate reinforcement (see **11.14.2**)

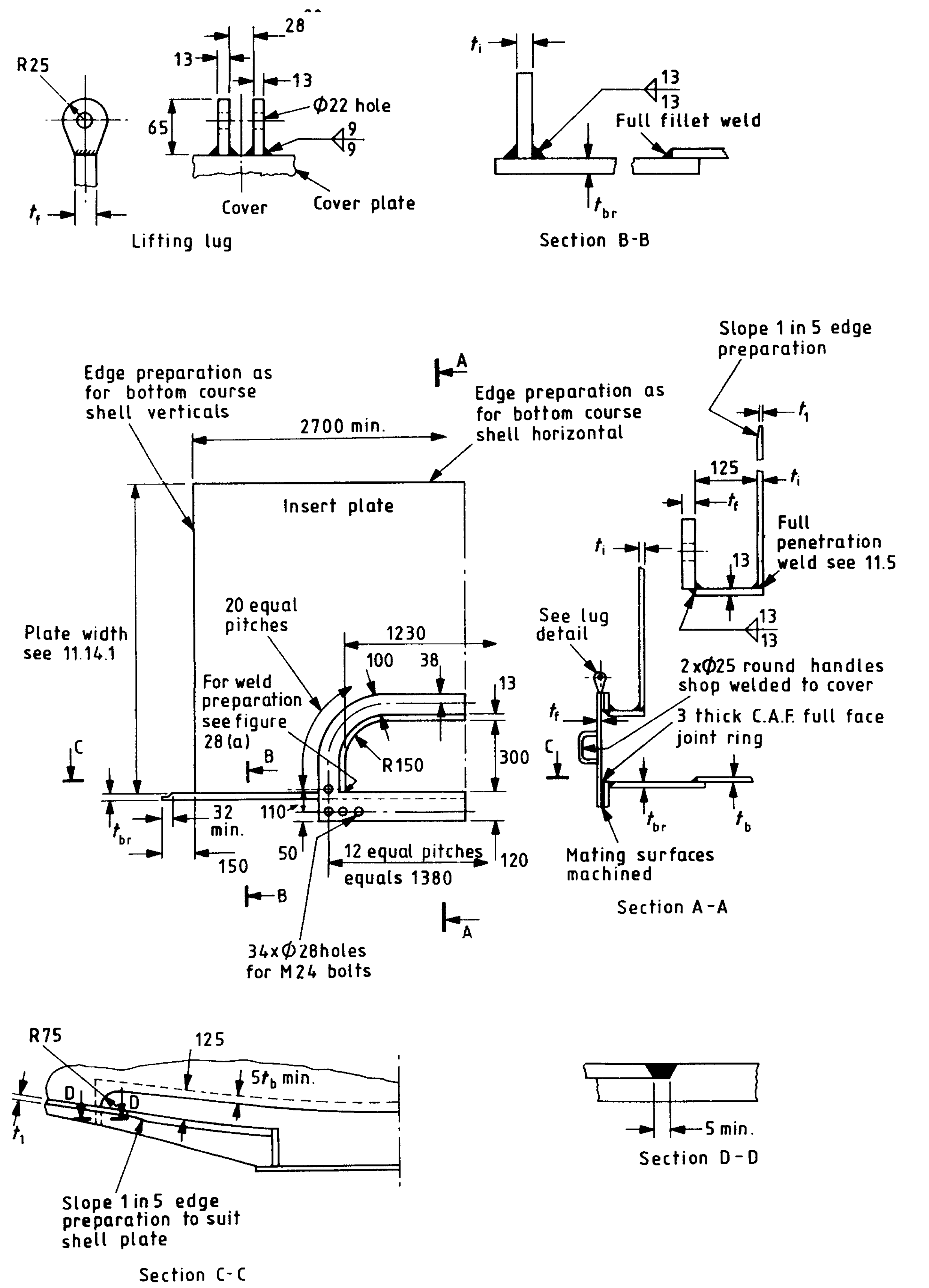
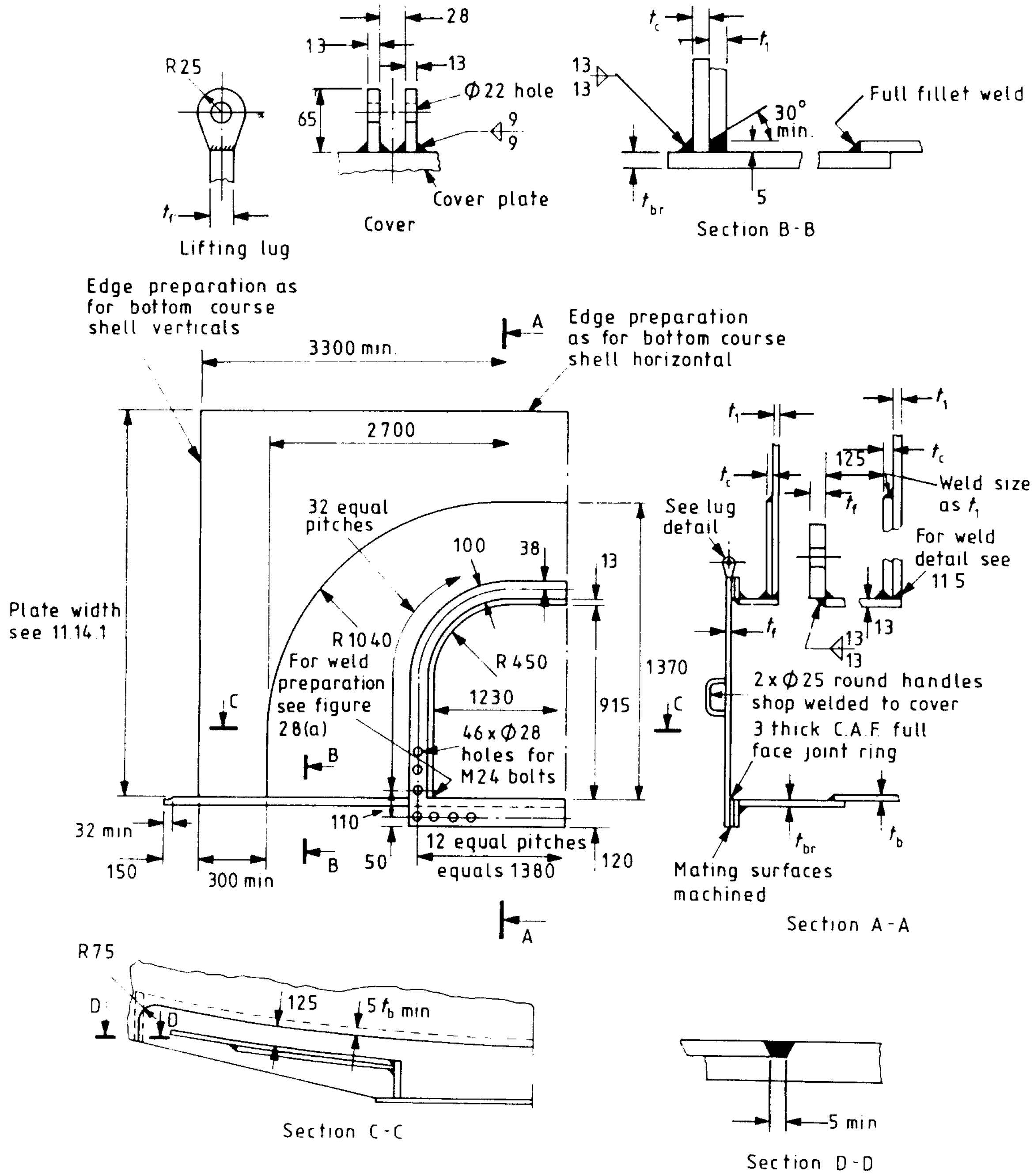


Figure 28 — Flush type clean-out door with insert plate reinforcement (see **11.14.2**) *(concluded)*

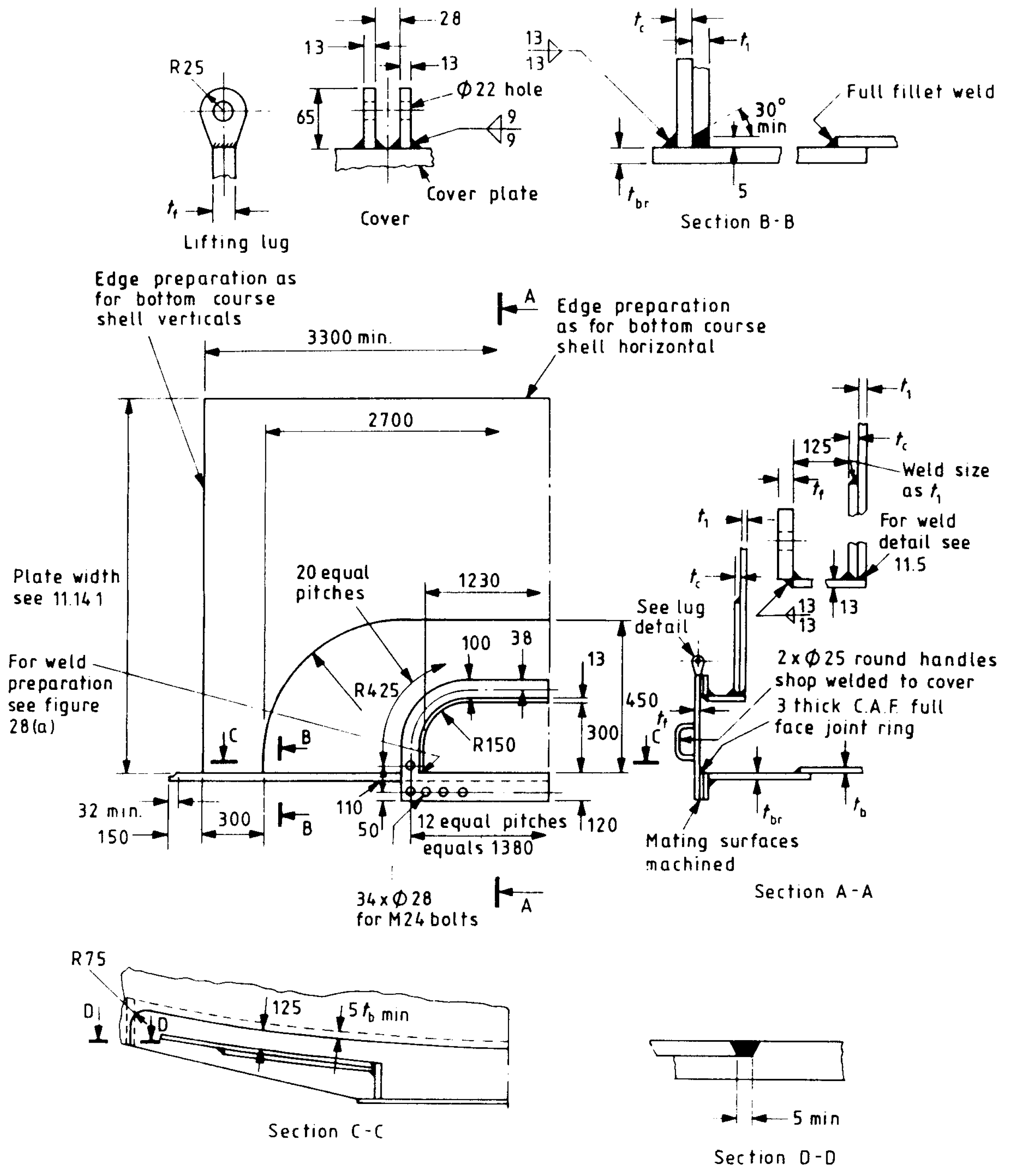


Key to symbols

t_1	is the bottom course shell thickness	$\leqslant$ 37 mm
t_c	is the thickness of 2.7 m reinforcing plate	$= t_1 + 3 \leqslant 40$ mm
t_f	is the thickness of cover and flange	$= 0.78H + 11$
t_{br}	is the thickness of bottom reinforcing plate	$= 7\sqrt{H} + 3$
t_b	is the tank bottom plate thickness	
H	is the tank height (in m)	

All dimensions are in millimetres, unless otherwise stated.
Fillet weld dimensions refer to leg length.

Figure 29 — Flush type clean-out door with plate reinforcement 915 mm × 1 230 mm
(see **11.14.2**)



Key to symbols

t_1 is the bottom course shell thickness ⩽ 40 mm

t_c is the thickness of 2.7 m reinforcing plate $= t_1 \leqslant 40$ mm

t_f is the thickness of cover and flange $= 0.52H + 6$

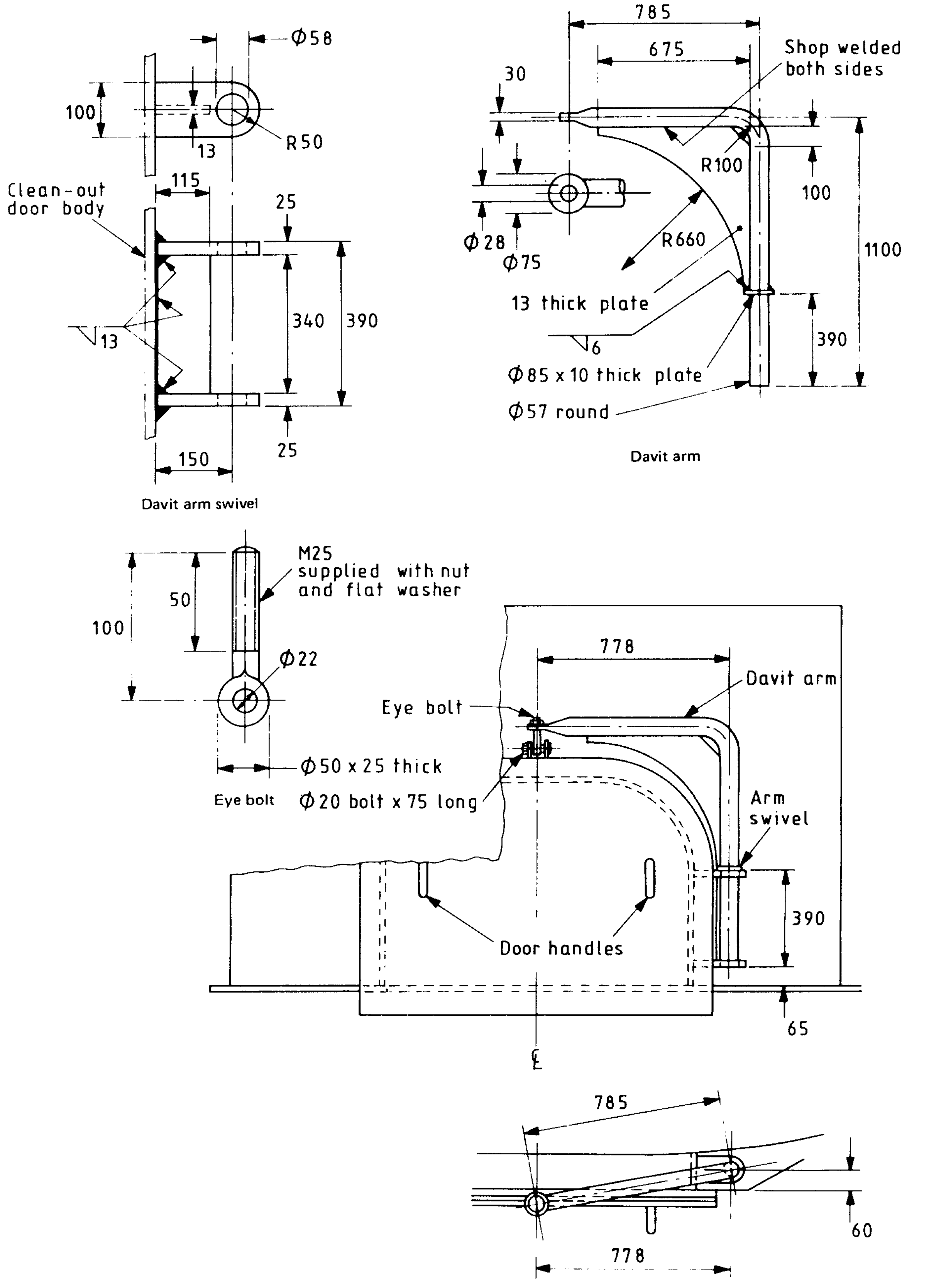
t_{br} is the thickness of bottom reinforcing plate $= 7\sqrt{H}$

t_b is the tank bottom plate thickness

H is the tank height (in m)

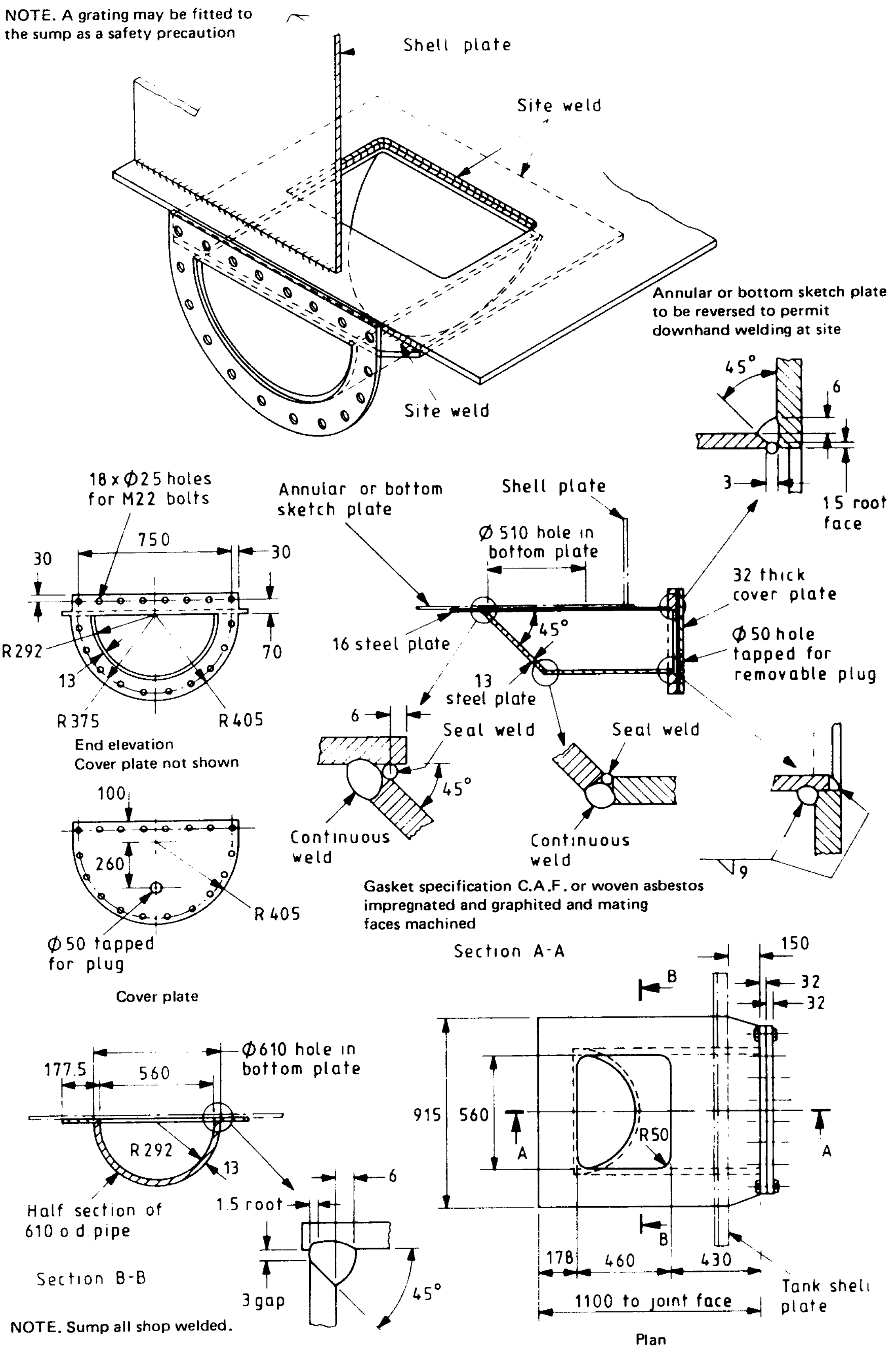
All dimensions are in millimetres, unless otherwise stated.
Fillet weld dimensions refer to leg length.

Figure 30 — Flush type clean-out door with plate reinforcement 300 mm × 1 230 mm
(see **11.14.2**)



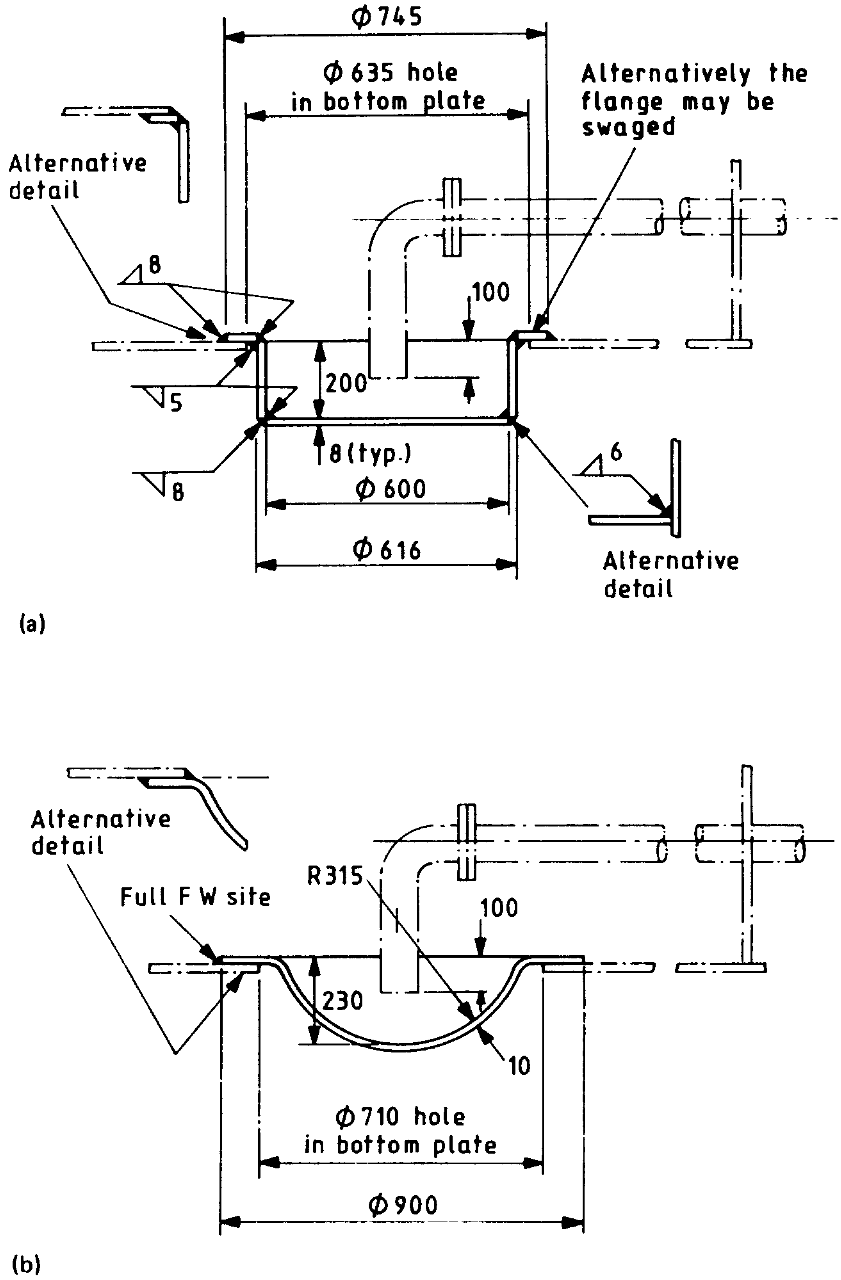
All dimensions are in millimetres.
Fillet weld dimensions refer to leg length.

Figure 31 — Davit for 915 mm × 1230 mm clean-out door (see **11.14.2**)



All dimensions are in millimetres.
Fillet weld dimensions refer to leg length.

Figure 32 — Combined water draw-off and clean-out sump (see **11.14.3**)



All dimensions are in millimetres.
Fillet weld dimensions refer to leg length.

Figure 33 — Acceptable water draw-off sumps (see **11.14.3**)

13 Shop fabrication

13.1 Workmanship

The workmanship and finish shall be subjected to close inspection by the manufacturer to ensure that they comply with all requirements of this standard.

NOTE This is required whether or not the purchaser waives any part of his inspection.

13.2 Hard stamping

Hard stamping shall only be permitted for the purpose of plate identification and in any case shall be kept to a minimum.

13.3 Plate edge preparation

13.3.1 All edges of all plates except bottom and roof plates, shall be prepared by shearing, machining, chipping or cutting with a machine-operated cutting torch. For butt-welded joints, shearing shall be limited to 10 mm thickness of plates.

13.3.2 For bottom and roof plates from a steel reversing mill, further edge preparation shall not be required.

The edges of the products of a steel strip mill shall be trimmed in accordance with **13.3.1** to achieve a square edge or double-run fillet welds shall be adopted to ensure adequate root penetration.

NOTE This requirement is necessary since the longitudinal edge produced by the mill may not be sufficiently square to ensure a sound fillet weld with full throat thickness.

13.3.3 When manual oxygen cutting is used for trimming outside circumferential edges of roof and bottom sketch plates, such oxygen-cut edges shall be properly cleaned for welding, free from oxide and cutting scale.

NOTE These should be reasonably smooth at the welding edges, although this would not normally require grinding if a good quality of workmanship is achieved.

13.3.4 All shell plates shall be profiled to a tolerance of ± 2.0 mm in length and width. In addition, to ensure that plates are truly rectangular, the diagonals, measured across the rectangle formed by scribing lines 50 mm from each edge, shall not differ by more than 3 mm.

For lap welded roof and bottom plates, normal mill tolerances shall be acceptable.

13.4 Rolling and pressing

When required, to comply with the dimensional requirements of this standard, shell plates shall have ends preset and be rolled to correct curvature.

NOTE If plates are not rolled, the manufacturer should inform the purchaser.

13.5 Bolt holes

All bolt holes shall be punched or drilled to template so that similar parts are interchangeable. Badly matched holes shall not be corrected by drifting.

13.6 Surface preparation and painting

13.6.1 Unless otherwise specified by the purchaser [see **3.2** i)], painting shall be as specified in **13.6.2**.

13.6.2 All roof structural members, stairways and handrailings manufactured from mild steel shall be thoroughly cleaned and freed from rust and scale by pickling, or blast cleaning, and painted immediately after cleaning with a primer coat of paint.

13.6.3 The method and extent of surface cleaning and painting for all other materials shall be specified by the purchaser [see **3.2** i) and **A.3.4**].

13.6.4 Special consideration shall be given to the need to protect welding margins, machined surfaces, nuts and bolts, etc. from corrosion during shipment and construction.

13.7 Erection marks (domestic market)

13.7.1 *Tanks erected by manufacturer.* All plates and structural members shall be marked in accordance with the manufacturer's normal practice, unless specified otherwise by the purchaser [see **3.2** j)].

13.7.2 *Tanks erected by others.* All plates and structural members shall be marked in accordance with a marking diagram to be supplied by the manufacturer which shall also bear such other marks as may be required to facilitate erection. Erection marks shall be painted clearly on plates and structural members in symbols at least 50 mm high, where practicable, and in the case of curved plates, such marks shall be on the inside surface.

13.8 Erection marks (export market)

All plates and structural members shall be marked in accordance with a marking diagram to be supplied by the manufacturer which shall also bear such other marks as may be required to facilitate erection overseas.

Erection marks shall be painted clearly on plates and structural members, in white paint and shall be at least 50 mm high. In addition, it may be necessary for them to be hard stamped (see **13.2**) in symbols not less than 13 mm high, which in the case of plates shall be in the corner approximately 150 mm from either edge. For curved plates, such marks shall be on the inside surface.

13.9 Packaging

13.9.1 *Structural materials and tank plates.* All materials to be erected either by the manufacturers or by others shall be bundled and packaged in accordance with the usual requirements for the mode of transport, taking into account the handling facilities available in transit, and every care shall be taken to guard against damage or loss.

13.9.2 *Mountings and fittings.* Where flange gaskets are packed separately, they shall be adequately protected against damage in transit.

NOTE Roof and shell manholes, nozzles, bottom sumps, clean-outs, etc. may be sent loose with covers bolted on.

13.9.3 *Welding electrodes.* Welding electrodes shall be supplied in containers which give adequate protection against damage and moisture in transit and in storage on site. The type of packing to be employed shall be specified by the electrode manufacturer.

NOTE *Identification.* Each case, bundle or package wherever possible should be provided with suitable identification marks giving weight or other desired particulars.

14 Site erection

14.1 General

Unless otherwise specified by the purchaser [see **3.2** k)], the responsibility for supplying welding electrodes and/or key plating equipment lies with the manufacturer. The responsibility for the supply of site erection equipment, labour, false work, etc. lies with the erection contractor.

14.2 Workmanship

The erector shall carry out an inspection of the workmanship and finish to ensure that they comply with all the requirements of this standard.

NOTE This will be completed irrespective of whether the purchaser waives any part of his own inspection.

14.3 Tank foundation construction

Unless he makes alternative arrangements [see **3.2** l)], the foundation for receiving the tank bottom shall be provided by the purchaser.

NOTE 1 It is recommended that its construction be in accordance with Appendix A. All reasonable care should be taken to prevent damage to the foundation during erection.

The top of the foundation levels shall be checked at a handover stage to the tank erection contractor and the difference in level of the surface of the tank foundation between any two points 10 m apart around the periphery of the tank shall not be greater than ± 6 mm and the envelope of peripheral surface levels shall lie within 12 mm above to 12 mm below the design levels.

NOTE 2 Closer tolerances in the tank foundation peripheral levels may be necessary in the case of floating-roof tanks. Uneven foundation conditions and settlement can result in the shell assuming an oval shape at the top, causing the floating roof to stick.

14.4 Rectification of damage to materials

Any damage to material shall be corrected to the satisfaction of the purchaser prior to erection [see **3.4** a)].

14.5 Erection of plates

14.5.1 The method proposed to hold the plates in position for welding shall be approved by the purchaser, unless such approval has already been given in writing by the purchaser [see **3.3** h)].

14.5.2 The course of shell plates to be erected first shall be held in position by metal clamps or other devices attached to the bottom plates whilst it is plumbed and checked for circularity and before it is tack welded or welded. In setting out this course, care shall be taken to ensure that due allowance is made for the contraction of the vertical joints during welding.

14.5.3 On all lap joints, the plates shall be held in close contact during the welding operation. The surfaces where the weld metal is to be applied shall be thoroughly cleaned before assembly.

14.5.4 Lugs attached by welding to the tank, and needed only for purposes of erection, shall comply with **11.16**.

14.6 Shell tolerances

14.6.1 The shell shall comply with **14.6.2** to **14.6.6**, which will ensure that the tank shell is being erected in a satisfactory manner in order that the completed tank will have an acceptable appearance and assist in maintaining the satisfactory function of a floating roof, if fitted.

14.6.2 The tolerances specified in **14.6.3** to **14.6.6** shall only apply to the tank during erection.

The location and number of tolerance measurements on the shell taken during erection and on completion shall be by agreement between the purchaser and the manufacturer [see **3.3** i)].

14.6.3 The internal radius measured horizontally from the centre of the tank at floor level shall not vary from the nominal internal radius by more than the following:

a) tanks ≤ 12.5 m diameter: ± 13 mm;

b) tanks > 12.5 m ≤ 45 m diameter: ± 19 mm;

c) tanks > 45 m diameter: ± 25 mm.

14.6.4 The overall height of the shell shall not be out of vertical by more than 1 in 200.

NOTE This standard of verticality should apply to each individual course which should be erected within the same tolerance.

14.6.5 Local departures from the design form shall be gradual and sharp changes in form shall not be permitted.

NOTE At horizontal and vertical joints the shell profile should not deviate from its design form by more than the following measured over a gauge length of 1 m:

a) plates ≤ 12.5 mm thick: 10 mm;

b) plates > 12.5 mm ≤ 25 mm thick: 8 mm;

c) plates > 25 mm thick: 6 mm.

14.6.6 Plates to be joined by butt welding shall be matched accurately and retained in position during the welding operation. Misalignment of the plates shall not exceed the following.

a) In completed vertical joints: 10 % of the plate thickness, or 1.5 mm for plates 19 mm thick and under, and 3 mm for plates over 19 mm thick, whichever is the larger.

b) In completed horizontal joints: 20 % of the upper plate thickness, or 1.5 mm for plates 8 mm thick and under, and 3 mm for plates over 8 mm thick, whichever is the smaller.

NOTE The tank shell should be checked for circularity, dimensions and level before the roof members are positioned or the primary wind girder is erected.

14.7 Floating-roof tolerances

The difference in the gap between the shell and the periphery of the roof on completion of erection of the roof shall not exceed ± 13 mm from the nominal gap.

NOTE At any elevation of the roof other than that at which it was erected, this difference in gap should not exceed ± 50 mm or such other value as may be agreed between the purchaser and the manufacturer for a particular seal design.

14.8 Manual oxygen cutting

14.8.1 If manual oxygen cutting is used for trimming outside circumferential edges of roof and bottom sketch plates and for trimming corners of bottom plates where two lapped joints intersect, such oxygen-cut edges shall be properly cleaned for welding and free from oxide and cutting scale.

NOTE These should be reasonably smooth at the welding edges although this would not normally require grinding if a good quality of workmanship is achieved. It is particularly important for the sketch to annular plate connection to be properly prepared and fitted for welding.

14.8.2 When openings for fittings fixed on site are manually oxygen cut, then radius arms, straight edges and nozzle guides shall be used. The cut edge shall be cleaned and trimmed by chipping or grinding where necessary to maintain the correct weld preparation.

14.9 Protection of shell during erection

The erection contractors shall employ suitable methods for the protection of the shell during erection which have been agreed with the purchaser [see **3.3** j)]. When required by the purchaser, full details of these methods shall be made available for his approval. The factors to be taken into account when determining the suitability of the proposed method of protection shall be:

a) tank size;

b) construction method;

c) location and degree of exposure to wind loads;

d) number and type of key plate equipment;

e) availability of reliable meteorological data during all periods of erection.

NOTE The use of steel wire guys or cables may not necessarily be adequate and consideration should be given to the use of temporary wind girders.

14.10 Erection of fixed roof

The temporary support for the erection of roof framing shall remain in position until the completion of the main and secondary framing. Care shall be taken when assembling roof sheets on the framing that no excessive unsymmetrical loading is applied to the roof members due to the stacking of roof sheets. The strength of the temporary support shall be calculated using the most unfavourable loading condition during erection.

When agreed with the purchaser [see **3.3** k)], roofs are permitted to be erected on the tank bottom and raised into position by an air pressure or other suitable means.

14.11 Erection holes

Erection holes shall not be permitted in plate work.

14.12 Final surface finish

The final surface preparation and painting system shall be specified by the purchaser in accordance with the environmental and operational conditions [see **3.2** i)].

15 Welding

15.1 Welding process

15.1.1 All welding, including repair, tack and attachment welding, shall be carried out according to the welding procedure established in **16.2** and by welders approved under **16.3**.

NOTE Unless otherwise agreed between the purchaser and the manufacturer, this standard is confined to manual metal-arc and multi-run submerged-arc welding processes for all seams. Additionally, CO_2 welding using spray transfer is permitted for welding girth seams only.

When it is proposed to utilize welding processes or techniques other than those specified in this clause, it may be necessary to modify or amplify the approval tests and/or inspection to ensure satisfactory results. For example, single-pass butt welds may introduce special notch ductility problems both in the weld metal and heat-affected zone and dip transfer welding processes could introduce lack of fusion and cold lapping which are not easy to detect. Additional tests and/or inspection will be the subject of agreement between the purchaser and the manufacturer.

15.1.2 Where manual metal-arc welding is employed in construction, hydrogen-controlled electrodes shall be used for welding steels with specified minimum tensile strengths greater than 430 N/mm^2 in thicknesses exceeding 13 mm.

15.2 Welding sequences

The sequences in which joints are to be welded shall be agreed between the purchaser and manufacturer [see **3.3** l)], and they shall be adhered to on site. The sequence employed for tack welding and welding the bottom, shell and roof plates shall be such that the distortion due to welding shrinkage is minimized.

15.3 Vertical joints

In vertical joints in shell plates exceeding 13 mm thick, all but the root runs shall be welded by the "upwards" technique. Root runs by either the "upwards" technique or by vertical-down, welding in such plates over 13 mm shall be permitted but, in the latter case, the weld metal shall be completely removed by gouging or other suitable means to sound clean metal, before welding on the reverse side.

15.4 Weather conditions

Welding shall not be done when the surfaces of the parts to be welded are wet, when rain or snow is falling on such surfaces, or during periods of high winds unless the welder and work are properly shielded. When the parent metal temperature is lower than 0 °C, the surfaces on both sides of the joint shall be preheated to a temperature warm to the hand, or to the temperature specified in the welding procedure, and to a distance of not less than four times the plate thickness or 75 mm, whichever is the greater, in any direction before welding is begun. During the course of the welding operation this preheat temperature shall be maintained in the specified area.

15.5 Preheating

The necessity for and the extent of preheat for any of the conditions shall be determined before the procedure tests are carried out.

NOTE Preheat is not normally necessary on plates less than 25 mm thick if the thermal input is not less than 1.6 kJ/mm and the material complies with clause 4.

For plates thicker than 25 mm and for all thicknesses if the thermal input derived from the welding process is less than 1.6 kJ/mm, the necessity for preheat shall receive special consideration (see BS 5135).

15.6 Electrodes

Electrodes shall be stored in their original packets or cartons in a dry place adequately protected from weather effects. Similar precautions shall be taken in the storage of flux for submerged-arc welding.

NOTE If the electrodes become damp but are not otherwise damaged, they may be used only after being dried out in a manner approved by the electrode manufacturer. Any electrodes which have areas of the flux covering broken away or damaged are to be discarded.

Hydrogen-controlled electrodes shall be stored and baked in accordance with the electrode manufacturer's recommendations.

15.7 Tack welds

Tack welds used in the assembly of the vertical joints of tank shells and horizontal joints to be manually welded shall be removed and shall not remain in the finished joint.

NOTE Tack welds in the bottom, shell-to-bottom, roof and automatically welded horizontal joints of the tank shell and other joints, need not be removed provided they are sound and the subsequent weld runs are thoroughly fused into the tack welds.

15.8 Cleaning of welds

Each run of weld metal shall be cleaned of slag and other deposits before the next run is applied. Slag shall also be removed from finished welds before inspection. Where air-arc gouging is used, the surfaces shall be chipped or ground back to bright metal before welding.

15.9 Back gouging and chipping

The reverse side of full penetration butt welds shall be cleaned thoroughly prior to the application of the first run to this side in a manner that will leave the exposed surface suitable for proper interfusion with the deposited weld metal.

NOTE This may be done by chipping, grinding, flame or air-arc gouging or, where the back of the initial bead is smooth and free from crevices which might entrap slag, by other methods which may, upon field inspection, be acceptable to the purchaser.

15.10 Visual inspection

All welds shall be visually inspected.

15.11 Weld reinforcement

The weld metal of both sides of all butt joints shall be built up so that the finished face in the area of fusion extends above the surface of the adjoining plates, or the thinner plate joined (see **16.2** and **16.3**).

15.12 Undercutting

The edges of all welds shall merge smoothly with the surface of the plane without a sharp angle. There shall be no undercutting of the parent metal, except that on horizontal butt joints and fillet welds, an undercut not exceeding 1 mm in depth shall not be cause for rejection.

15.13 Peening

Peening of butt welds shall not be permitted.

15.14 Repairs

15.14.1 All unacceptable defects found in welds shall be brought to the attention of the purchaser and his approval shall be obtained as to the method of repair [see **3.4** b)].

15.14.2 When a section of weld is shown by radiography not to comply with this standard, two adjacent spots shall be examined by radiography.

If the weld at either of these sections fails to comply with **17.4.10**, then either of the following courses shall be followed:

a) additional nearby spots shall be examined until the limits of such welding are determined; *or*

b) all welding performed by the welder in that joint shall be replaced.

In case a), if any additional spot fails to comply with **17.4.10** the limit of such welding shall be determined as specified for the initial section of the defective weld. For case b), the purchaser shall be permitted to request that one radiograph be taken at any selected location on any other joint that the same welder has welded [see **3.4** c)].

15.14.3 All defects in excess of the minimum requirements specified in **17.4.10** shall be removed by chipping, grinding or gouging from one or both sides of the joint, as required, and rewelded. Only sufficient cutting-out of the joints shall be done' as is necessary to remove the defects.

15.14.4 All repairs carried out because of non-compliance with **17.4.10** shall be 100 % radiographed unless the complete seam is removed and rewelded; in which case the original weld inspection procedure shall be followed.

16 Welding procedure and welder approval

16.1 General

16.1.1 The welding processes to be used for the construction of the tank shall be used in the procedure and welder approval tests.

16.1.2 All welding procedures shall be approved in accordance with **16.2** and all welders shall be approved in accordance with **16.3**.

16.1.3 Previously approved procedures shall be acceptable as agreed between purchaser and manufacturer [see **3.3** m)].

16.2 Welding procedure approval

16.2.1 *Procedure details.* The welding procedure specification shall be in accordance with the requirements of BS EN 288-2 and shall give all details of the welding processes to be used by the contractor, including those for repair, tack and attachment welds. The welding procedure specification shall be substantiated by a welding procedure test, undertaken by the manufacturer, either:

— in accordance with BS EN 288-3;

or

— a pre-existing weld procedure test performed to BS 4870-1 previously approved, except that the range of approval of this test shall be in accordance with the ranges in BS EN 288-3.

16.2.2 *Number and types of test plates.* The number and types of test plates shall be in accordance with BS EN 288-3 and this standard. When steels with specified minimum tensile strengths greater than 490 N/mm^2 are used in construction, the highest tensile grade of steel to be used in construction shall be used in approval testing.

Procedure tests for nozzle (stress relieved or as welded) repair, tack and attachment welds are not normally required provided the process and consumables have been approved on a weld test plate in accordance with BS EN 288-3.

16.2.3 *Examination of test plate.* Each butt-welded test plate shall be prepared and subjected to non-destructive testing in accordance with BS EN 288-3.

16.2.4 ***Destructive testing***

16.2.4.1 *General.* Destructive testing shall be in accordance with BS EN 288-3.

Where impact testing of the plate material is specified (see **4.4**), then impact testing of the weld metal shall be carried out.

16.2.4.2 *Impact tests.* Charpy V-notch impact test specimens shall be selected, machined and tested as shown in Figure 34 and in accordance with BS 131-2.

The weld metal of vertical shell butt welds and of manual metal arc welded shell butt welds, including the connections between nozzles and mountings and the shell, shall meet 27 J minimum average Charpy V impact energy at the same test temperature as required by **4.4** for the plate material. When connections are made between materials of different thickness, the reference thickness for Figure 1 shall be that of the thicker part joined.

When girth seams are welded by an automatic process, the Charpy V impact energy shall not be less than 27 J minimum average at – 10 °C or at a temperature indicated by Figure 1 using scale A, whichever is the least onerous. 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.

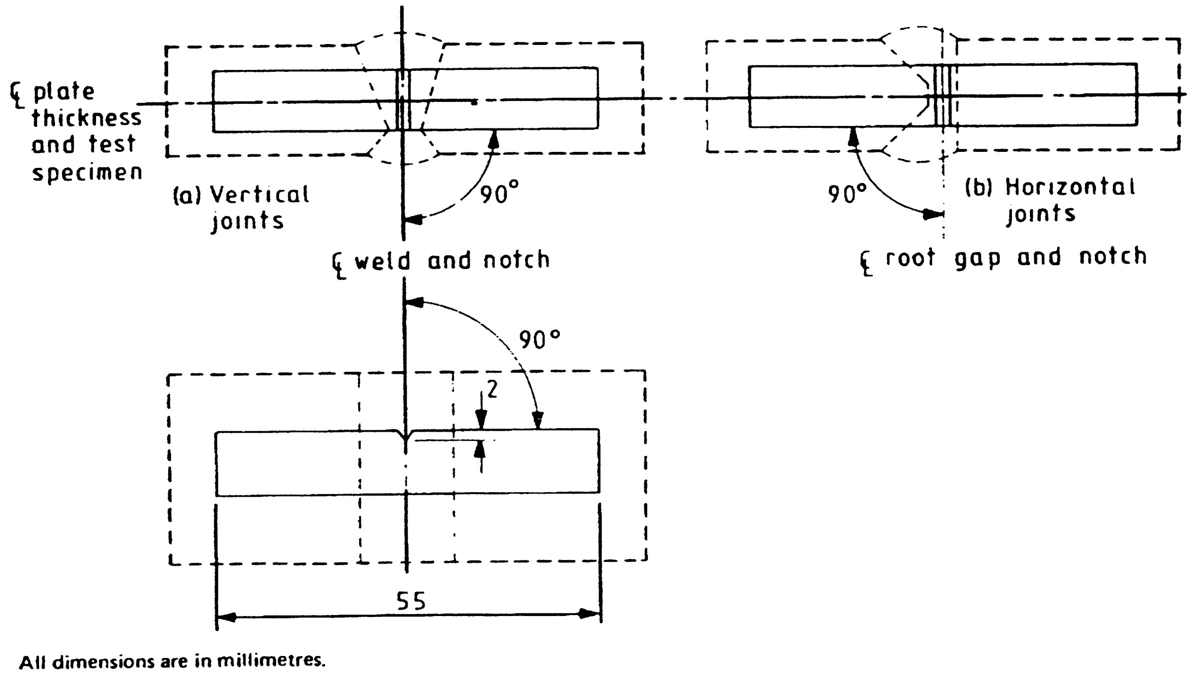


Figure 34 — Location of Charpy V-notch impact test specimen (see **16.2.4.2**)

16.2.4.3 *Retests.* If one or more Charpy specimen fails to comply with **16.2.4.2**, three further specimens shall be prepared and tested.

If any of the retests fail to comply with **16.2.4.2**, the procedure shall be deemed not to comply with this standard and a new procedure shall be tested.

NOTE *Hardness.* It is recommended that it is demonstrated in the procedure tests that the hardness of the heat-affected zone at the shell to bottom plate and of the weld metal, heat-affected zone and parent plate at other locations in the shell, should not exceed 300 HV (using 30 kg load).
Where wet H_2S conditions are to be encountered and an appropriate low level of hardness cannot be obtained, the most suitable way to avoid stress corrosion cracking will be to protect the shell to annular weld area and the adjacent vertical shell and annular plate welds using an appropriate paint.

16.2.5 *Changes affecting approval.* A welding procedure test shall be required when any of the changes specified in BS EN 288-3 and/or the following are made to an approved welding procedure.

a) A change of brand of hydrogen-controlled welding electrode or in automatic welding consumables, except for the wire in submerged-arc welds.

b) For a specified weld preparation in plates 12.5 mm thick and thicker, a change of more than ± 25 % in the number of runs. If the cross-sectional area of the groove is increased, it is permissible to increase the number of runs in proportion to the increase in area.

c) For automatic girthseam welding, a change from multiple runs per side to single run per side.

d) For automatic girthseam welding, a change from single arc to multiple arc or vice-versa.

16.3 Approval process for welders

16.3.1 *Approval of welders.* Each welder shall be approved before welding on the tank. A welder who has successfully welded the procedure test plate shall be considered to have been approved.

16.3.2 *Approval tests.* Each welder shall be approved in accordance with BS EN 287-1 and this standard, except for the following applications.

a) Unless specifically required by the purchaser [see **3.2** m)], a welder who is only required to make fillet welds on the tank bottom, roof or shell plates not exceeding 12.5 mm thickness, except for the shell-to-bottom weld, is not required to pass an approval test, but his standard of workmanship shall be such that the requirements of this standard are maintained.

b) Tack welding of shell, roof or bottom, where the tack weld shall be removed by gouging or shall be completely fused, can be carried out by non-approved operators who are suitably instructed and supervised to the purchaser's satisfaction when permitted by the purchaser [see **3.2** n)]. Otherwise, approved welders shall carry out these operations.

16.3.3 *Examination of welders' test plates.* Each butt-welded test-plate shall be tested in accordance with BS EN 287-1.

16.3.4 *Extent of approval.* A welder who has successfully welded the specified tests shall be approved to the extent specified in BS EN 287-1 except that:

a) a welder who has successfully welded the tests using a basic coated electrode shall be approved to use rutile, cellulosic or iron powder coated electrodes;

b) a welder who has successfully welded the tests using a rutile coated electrode shall be approved to use cellulosic or iron powder coated electrodes;

c) a change from single arc to multiple arc or vice versa for welders operating automatic or semi-automatic machines requires re-testing.

16.3.5 ***Records***

16.3.5.1 Copies of the records of each welder's approval shall be available for examination on site by the purchaser [see **3.4** d)].

16.3.5.2 A welder who has been approved shall not be prevented from undertaking production work pending examination of these records, or certified copies of these records, provided **16.3.5.1** has been complied with.

17 Radiography

17.1 Application

The procedure specified in this clause shall apply to the inspection of the joints listed in **17.3**. Radiographic examination of fillet welds shall not be required.

17.2 Preparation for examination

Surface dressing of butt-welded seams is not normally required except that surface irregularities which may confuse or mask any objectionable defect shall be carefully removed.

17.3 Extent of radiography per tank

17.3.1 The extent of radiography shall be not less than that listed in Table 6 for each plate thickness, but shall include one radiograph taken from the first completed vertical joint for each welding process and thickness, if differing by more than ± 3 mm, welded by each welder. Thereafter, without regard to the number of welders working thereon, the same incidence of radiography shall be maintained.

NOTE The location of the radiographs is to be determined in agreement with the purchaser.

17.3.2 Butt welds around the periphery of an insert plate shall be radiographed over the whole of their length.

NOTE When two or more tanks are erected in the same location for the same purchaser, either concurrently or consecutively, the initial radiographs of the work of each welder need only be taken on one tank. In addition, the total number of radiographs taken may be based on the aggregate length of welds for the same type and thickness in such a group of tanks rather than on the length in each tank, but with a minimum of 50 % of the coverage requirements given in Table 6 on each tank.

17.4 Radiography procedure

17.4.1 *Techniques.* Radiogrphy shall be carried out in accordance with BS 2600-1 using techniques 1, 2, 3, 6 or 7 for plate thicknesses up to and including 19 mm and techniques 1 or 2 for plates thicker than 19 mm.

NOTE X-radiography is preferred to gamma-radiography because of the inherent low contrast of the latter. If, because of local conditions or special circumstances, gamma-radiography is used the isotope employed will be Iridium 192.

Table 6 — Extent of radiography per tank

Thinner plate thickness	Vertical welds and T-joints	Horizontal seams	Annular bottom butt welds[a]
Over 25 mm	10 % of total seam length plus all T-junction[b]	2 % of seam length	—
Over 13 mm up to and including 25 mm	10 % of total seam length, at least half of the radiographs to include T-junctions	2 % of seam length	—
Up to and including 13 mm	1 % of total vertical seam length	1 % of seam length	—
Annular plates over 10 mm	—	—	All joints
Annular plates over 8 mm up to and including 10 mm	—	—	Half the number of joints
Annular plates up to and including 8 mm	—	—	A quarter of the number of joints, with a minimum of 4 radiographs

[a] The length to be radiographed shall consist of that length from the outside of the annular plate to a point 250 mm inside the tank.
[b] 50 % of radiographs with film horizontal and 50 % of radiographs with film vertical.

17.4.2 *Intensifying screens.* Lead screens shall be used in all the techniques and their thicknesses shall be in accordance with Table 3 of BS 2600-1:1983.

17.4.3 *Radiographic film.* Each film shall show clearly a minimum of 300 mm of weld length; it shall be centred on the weld and shall be sufficiently wide to permit adequate space for the location of identification markers and image quality indicator (IQI). Care shall be taken to ensure that films are carefully handled and stored; they should not be subjected to mechanical or chemical damage and it is particularly important to guard against inadvertent exposure to sunlight, radiation or excessive heat.

17.4.4 *Standard test radiograph.* The exposing, film processing and handling procedures shall be demonstrated to the purchaser and shall be subject to his approval [see **3.4** e)]. A standard test radiograph shall be prepared and shall be made available for inspection.

17.4.5 *Image quality indicators.* To check the degree of definition and contrast achieved and to determine whether the minimum radiographic standard is being attained, an image quality indicator complying with BS 3971 shall be used with dimensions appropriate to the thickness of the weld. The method of assessing the radiographic sensitivity shall be that described in BS 3971.

17.4.6 *Film location.* The film during exposure shall be as close to the adjacent weld surface as is practicable.

17.4.7 *Identification markers.* Identification markers, the images of which will appear on the film, shall be placed adjacent to the weld at each spot examined and their locations accurately marked near the weld on the outside surface, so that a defect appearing on the radiograph may be accurately located.

17.4.8 *Reference marker.* There shall also be a suitable reference marker on each film.

17.4.9 *Submission of radiography.* All radiographs shall be submitted to the purchaser.

17.4.10 *Radiographic standards.* The defect acceptance levels given in Table 7 shall be imposed during fabrication as a means of quality control. Areas found to be outside these limits shall be repaired in accordance with **15.14**.

17.4.11 ***Record of radiographic examination***

17.4.11.1 The erection contractor shall make a record of all films, with their identification marks, preferably on a developed shell plate diagram.

NOTE Other agreed methods comparable with this diagram may be acceptable.

17.4.11.2 After completion of the tank, the films shall be retained for a minimum of 5 years.

Table 7 — Acceptance levels for radiographic examination

Defect type	Permitted maximum
Crack	Not permitted
Lack of fusion	Not permitted
Incomplete penetration	Not permitted except as specified in **7.5.2**
Isolated pores	$\phi \not> t/4$
Uniformly distributed or localized porosity	2 % by area[a] (as seen in a radiograph)
Linear porosity	Linear porosity in vertical welds parallel to the axis of the weld may indicate lack of fusion or lack of penetration and therefore is not permitted
Wormholes, aligned	Length $\not>$ 6 mm
Wormholes, aligned	As linear porosity
Individual slag inclusions parallel to major weld axis NOTE 1 Inclusions to be separated on the major axis by a distance equal to or greater than the length of the longer inclusion and the sum of the lengths of the inclusions shall not exceed the total weld length being examined	Length $\not> t$
NOTE 2 In this table the following symbols are used: ϕ is a defect diameter (in mm); t is the thickness of thinner plate being joined (in mm).	
[a] Area to be considered should be the length of the weld affected by porosity multiplied by the maximum width of the weld locally.	

18 Testing

18.1 General

18.1.1 A comprehensive test procedure shall be specified and agreed between the purchaser and manufacturer [see **3.3** n)]. The water test procedure shall specify maximum filling rates, hold periods, emergency and normal emptying procedures, method of settlement measurement, limits for differential and maximum settlement of the foundations, minimum water temperatures, etc. (see **A.5**).

On completion of the test, the manufacturer in conjunction with the purchaser shall review the settlement data and determine that the tank is fit for service. Consideration shall also be given to the effect of future settlements.

18.1.2 No connections shall be made between a tank and any product line until the tank and its appropriate mountings have been satisfactorily tested in accordance with **18.2** to **18.6**

18.2 Bottom testing

18.2.1 The bottom of the tank shall be tested for leaks using either of the methods in **18.2.2** or **18.2.3**

18.2.2 The bottom seams shall be tested by the vacuum box method using a pressure of 650 mbar absolute (i.e. 350 mbar of vacuum).

18.2.3 Alternatively, after the tank bottom and at least the bottom course of shell plates have been welded, air shall be pumped beneath the tank bottom at a pressure sufficient to lift the bottom plates off the foundation. The pressure, which shall be 7 mbar maximum, shall be held by the construction of a temporary dam of clay or other suitable material around the tank periphery. Soap solution or other suitable material shall be applied to the joints for the detection of leaks.

18.2.4 The bottom and bottom-to-shell welds shall be made free of leaks as required by the purchaser [see **3.4** f)].

18.3 Mountings

18.3.1 Pneumatic testing of the reinforcing plates is not required unless specified by the purchaser [see **3.2** o)], when it shall be done at a pressure of 1 bar prior to the shell water test. For this purpose, tapped holes of 12 mm diameter maximum shall be used and these holes shall be left open after testing.

18.3.2 The roof drain shall be installed prior to the hydraulic test on the tank and during this test the drain shall be examined to ensure that it is not leaking due to external pressure.

18.4 Shell testing

18.4.1 The tank shall be tested by filling with water to the level specified in **7.2.1**. The rate of filling shall not exceed. that specified in the procedure.

NOTE Attention is drawn to the notes of Figure 1 relating to the minimum test water temperature and to the recommendations of **A.5** relating to the rate of test water filling.

18.4.2 The manufacturer shall be informed by the purchaser of the quality of the water to be used and if necessary, any special cleaning or corrosion protection, e.g. inhibitor or cathodic protection [see **3.1** k)].

18.4.3 Continuous inspection shall be maintained for the whole filling period. All leaks found shall be repaired with the water level at least 300 mm below the point being repaired.

18.4.4 During emptying of test water, precautions shall be taken to ensure that the design vacuum is not exceeded.

18.5 Floating-roof testing

18.5.1 The centre deck plate, pontoon bottom plate and rim plate welded joints shall be tested by spraying with a penetrating oil, such as light gas oil, on the bottom side and inspecting visually on the top side and inside of rim plates.

18.5.2

18.5.2.1 Either of the methods of test specified in **18.5.2.2** or **18.5.2.3** shall be applicable.

18.5.2.2 The fillet welds connecting the bulkheads between pontoons to the inner and outer rim plates and to the pontoon bottom shall be examined for leaks using penetrating oil prior to the installation of the pontoon top plates. When continuously welded, the welds connecting the pontoon top plates shall be inspected visually for pinholes or defective welding.

18.5.2.3 Alternatively, when the compartments are completely welded, each completed compartment of pontoon roof shall be individually tested with an air pressure of 7 mbar gauge, a soapy water solution being applied to all welded joints under pressure which have not been previously tested with penetrating oil.

18.5.3 The roof shall be given a flotation test while the tank is being filled with water and emptied. During this test, the upper side of the lower deck and all pontoon compartments shall be examined for leaks. Rainwater shall be prevented from entering the pontoon compartments during this test.

During the initial filling with product the purchaser shall check pontoon compartments and decks for any leaks caused by the deeper immersion in the stored product than in the water [see **3.4** g)].

18.5.4 Pin-holes and/or defective welding in seams intended to be in contact with the product shall be corrected by welding.

NOTE Isolated pin-holes in seams not in contact with the product may be caulked mechanically.

18.5.5 The sealing mechanism shall be checked to ensure proper functioning over the full height of the shell.

18.6 Fixed-roof testing

18.6.1 When the tank shell is tested with water the roof joints shall be tested by applying an internal air pressure equal to 7.5 mbar for non-pressure tanks and 3 mbar above the design pressure of the tank for pressure tanks.

In the case of column-supported roof tanks, the air test pressure shall be limited to that pressure equivalent to the weight of the roof plates unless the compression area has been determined in accordance with **8.5**, using a design pressure of 7.5 mbar (see **2.1.2**).

Soap solution or other suitable material shall be used for the detection of leaks.

NOTE Attention is drawn to the need for careful control and monitoring of pressures during this testing. Climatic changes can cause sharp fluctuations in test pressures and provision should be made for the safe relief of pressure or vacuum in the event of such fluctuations.

18.6.2 Pressure and vacuum or free vents shall normally be installed after completion of the tank water test or alternatively shall be blanked-off during the testing of the roof. After installation or immediately following the roof pressure test all vents shall be carefully examined to ensure that all packing and blanks have been removed and that all moving parts function normally.

NOTE 1 *Anchorages*. If tank anchorages are provided, these should be checked and readjusted, if necessary, with the tank full of water and prior to the air pressure test.

NOTE 2 *Foundations*. Attention is drawn to the recommendations of **A.5** When foundations are not constructed in accordance with Appendix A it is still advisable that the recommendations in **A.5** are adhered to.

Water filling should be stopped immediately there is evidence of excessive abnormal or unexpected soil movement or the differential or maximum settlements are tending to exceed those specified in the testing procedure. If there is a risk of continuing excessive settlements or soil movement, the tank should be off-loaded.

Any tank showing evidence of leakage from the bottom during water test should be emptied immediately. The source of such leaks should be determined and rectified. Where there is a risk that the leakage may have caused washout of the foundation material, the foundations are to be inspected. The repair of the foundation should be the subject of special consideration and approval by the purchaser.

Appendix A Recommendations for tank foundations

A.1 General

A.1.1 The recommendations given in this appendix are intended to establish general principles for the design and construction of foundations under vertical oil storage tanks. They are offered as an outline of good practice and point out some precautions which should be observed in constructing such foundations.

A.1.2 Because of the wide variety of surface, sub-surface and climatic conditions, it obviously is not practicable to establish design data to cover all situations and the allowable soil loading should be decided for each individual case having regard to the type and size of tank. The design should be generally in accordance with CP 2004 and take account of the special nature of the soil/structure interactions and the definition of the load.

A.1.3 If tank anchorages are required according to clause **10**, suitable foundations are required. The design of these foundations should be based on the loadings specified by the tank designer.

A.2 Site design considerations

A.2.1 At any tank site, the nature of the sub-surface conditions should be known in order to determine the variation of soil properties over the site and to estimate the amount of settlement that will be experienced. A site investigation should be carried out in accordance with BS 5930 to identify the ground conditions under the complete area of each tank to a depth over which significant settlements may occur. Where the founding material is sound or weathered rock, the site investigation shall be supplemented by geophysical mapping of the tank pad formation.

Additional useful information can be obtained from a review of sub-surface conditions and the history of similar structures in the vicinity.

The allowable soil loading can then be decided in relation to the reliability of predictions of ultimate bearing capacity and the permissible settlements by a soil mechanics specialist.

A.2.2 The permissible settlement is the maximum allowable design limits for the settlement of the foundation. These limits are to be agreed between the purchaser and the manufacturer for the maximum and differential settlement across the bottom and around the periphery of the tank. The considerations affecting the limits of permissible settlement are as follows.

a) The dimensions and aspect ratio of the tank.

b) The type of tank, e.g. open-top tanks with pontoon type floating roofs will generally tolerate a much smaller differential settlement around the circumference than fixed-roof tanks Tanks with column-supported roofs require special design considerations in the event of significant bottom plate settlements (see **8.2.1**).

c) Economic considerations, e.g. savings of foundations costs versus the risk of excessive settlements and the possibility of future maintenance costs.

d) The allowable relative movement of adjoining, or related foundations or pipework.

e) The difference in settlement between the periphery and the centre.

Settlement calculations are of limited accuracy even with detailed investigation and sophisticated analysis. Tanks should not therefore be designed to depend for their integrity on precise settlement predictions.

A.2.3 Maximum tank settlements can vary from a few millimetres to a metre or more. The initial settlement measured at water test can be greatly exceeded during the life of the tank particularly on weak slow draining sub-soils and the amount of settlement may also be affected by the cyclic nature of the load. The extent of the differential settlement will depend on the uniformity or otherwise of the sub-soil, the stiffness of the tank and any interactive effects from adjacent tanks. The use of foundations with large permissible settlements should only be considered after a thorough site investigation and in consultation with soil mechanics specialists.

The following are some of the many variations in conditions which should, if at all possible, be avoided for the construction of tank foundations. Where, from economic considerations or lack of alternative areas, they are unavoidable, then they require special considerations.

a) Sites where part of a tank may be on rock, undisturbed ground or other construction and part on fill; where the depth of required fill is variable; or where ground under part of the tank area has been precon-solidated.

b) Sites on swampy or filled ground, or where layers of highly compressible material are below the surface.

c) Sites where stability of the ground is questionable, such as adjacent to water courses, deep excavations or heavy loads, or on hillsides.

d) Sites where tanks may be exposed to flood waters, resulting in possible uplift, displacement or scour.

Special consideration should also be given to the effect on the foundation of heated tanks.

A.2.4 If the sub-soil supporting the foundation is weak and inadequate to carry the load of the filled tank without excessive settlement, the following methods should be considered.

a) Removal and replacement of unsatisfactory material by suitable compacted fill.

b) Improvement of the soft or loose materials by vibration, dynamic compaction or preloading with an overburden of other material.

c) Sub-soil drainage with or without preloading.

d) Stabilization by chemical or grout injection methods.

e) Provision of a reinforced concrete raft with or without supporting piles.

A.3 Typical tank foundation pad

A.3.1 A typical tank foundation pad, an example of which is illustrated in Figure 35, is described in **A.3.2** to **A.3.6**.

A.3.2 The material in a typical foundation and to replace any unsatisfactory underlying soft spots, should be sound, clean and durable. It should bind to form a dense surface when laid in 150 mm layers and rolled with a 6 tonnes to 10 tonnes roller. The top surface of the pad should incorporate a stable permeable granular drainage layer.

The core of the pad can be constructed from any highly compactable, chemically inert, locally available material that is not susceptible to frost heave, is non-corrosive and is of low compressibility and sufficient strength. An annular ring of coarse granular material may be required to provide high edge load resistance when the locally available material has low strength except when confined, e.g. most sands. The annular ring may also be required to prevent wash-out of fine soils in the event of a bottom leak and provide protection against erosion around the tank, perimeter.

A.3.3 It is suggested that the surface upon which the tank bottom will rest be constructed to a height of a minimum of 300 mm plus the expected settlement above the surrounding ground level. The surface of the completed foundation should be sloped up from the periphery to the centre: a slope of 1 in 120 is recommended as a minimum. On poor soils, this slope should be increased to compensate for extra settlement at the tank centre (for "cone-down" bottoms, see **A.4.2**).

A.3.4 When the profile of the surface is complete it should be covered with a smooth bitumen-sand mix that is 50 mm thick to weatherproof the foundation and provide a layer sufficiently firm to carry the necessary traffic and facilitate welding of the bottom plates. This layer will also retard corrosion of the tank bottom. Mill scale should have been removed from the underside of the bottom plates to minimize corrosion [see **3.2** i)]. This bitumen-sand surfacing should extend outside the tank periphery to protect the external surface of the foundation and may need re-trimming after the water test and from time to time during operation to maintain suitable water drainage away from the tank. Bitumen-sand surfacing should be omitted where cathodic protection of the tank bottom is adopted.

A.3.5 A suitable bitumen-sand can be produced by hotmixing in the following proportions by mass:

a) 9 ± 0.5 % (*m*/*m*) non-toxic cut back bitumen (i.e. fluxed with kerosine and not creosote[7]);

b) 10 ± 1.0 % (*m*/*m*) filler: either limestone dust passing a sieve of nominal aperture size 75 μ complying with BS 410, or Portland cement;

c) 81 ± 1.5 % (*m*/*m*) clean dry washed sand with the properties given in Table 2 of BS 882, BS 1201-2:1973.

As an alternative to the sand, crushed rock types 1 to 7, slag or limestone in accordance with Table 53 of BS 4987:1973 may be used.

Some variation of these proportions may be necessary to suit ambient temperature conditions, locally available materials, etc., and it is recommended that trial mixes be made in order to achieve the correct proportions to suit the particular case.

A.3.6 A series of 75 mm diameter PVC pipes should be placed around the perimeter of the drainage layer and protrude through the bitsand facing to the berm to give warning of any bottom plate leakage. The pipes should be at not more than 5 m intervals and the inlet should be covered with a mesh screen to prevent clogging by material from the drainage layer. In special cases it may be necessary to introduce an impermeable layer below the base of the foundation pad (see Figure 35).

[7] Creosote fluxed bitumen is not considered to be acceptable in view of its acid content.

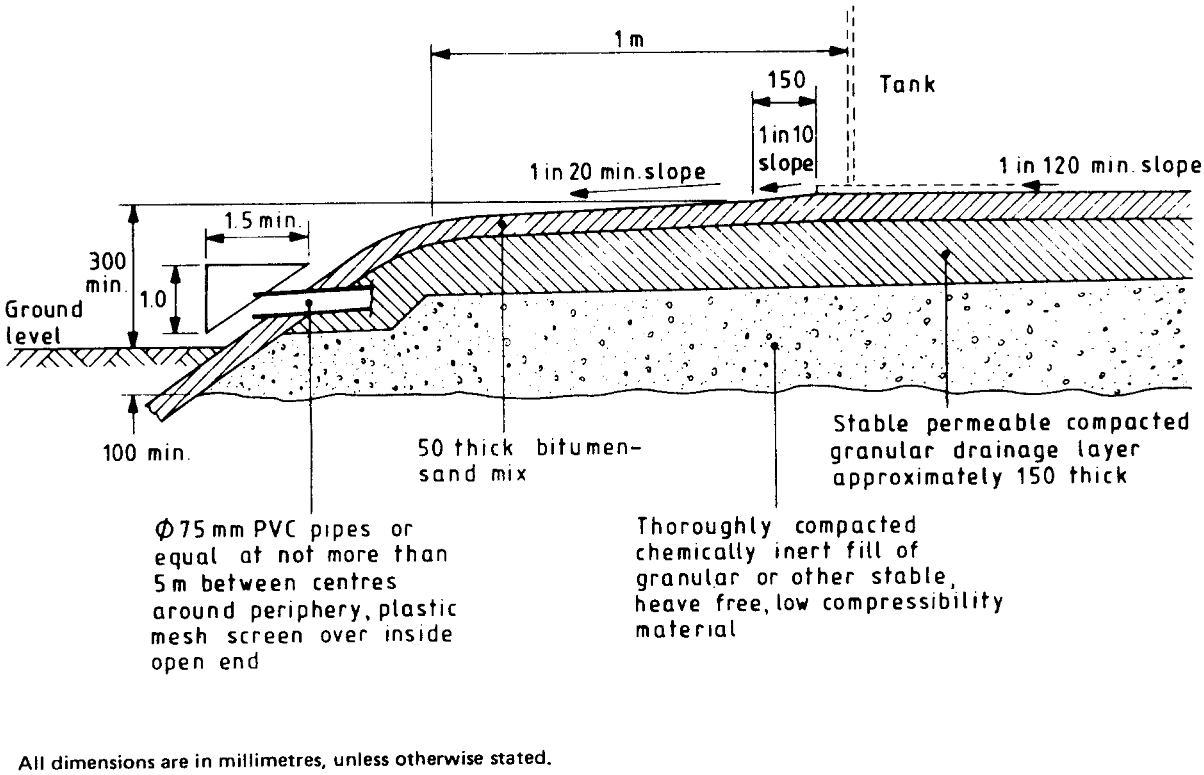


Figure 35 — Typical tank foundation

A.4 Modifications and alternatives to typical foundation pads

A.4.1 Where poor sub-soil conditions necessitate the use of a reinforced concrete raft and piled foundations, the raft should be designed in accordance with normal reinforced concrete practice (see CP 114 or CP 110) and surfaced with a reduced thickness of bitumen-sand mix as described in **A.3**.

A.4.2 Where a tank with a central internal bottom drainage sump is required:

a) on hard ground where little settlement is expected, the tank foundation may be given a slight fall to the centre;

b) on poor ground where considerable settlement is expected, special consideration should be given to the possibility of unacceptable tensile stresses developing in the bottom plates and in such cases a foundation constructed as recommended in **A.4.1** should be used.

A.4.3 For high-pressure tanks, it may be necessary to prevent uplift of the shell due to the combined effects of vapour pressure and wind movement by means of an anchorage around the shell built into a suitable concrete ring or raft.

Where the foundation design incorporates a ring beam, care should be taken to ensure that the relative settlement characteristics of the ring wall and the infill are not such as to result in excessive differential settlement local to the inner wall of the ring beam. Consideration may need to be given to the provision of a hinged transition slab in this area. A minimum thickness of 50 mm of bitumen-sand should be maintained over the concrete.

A.5 Water testing

While it is normal practice to test all tanks by filling with water before commissioning, this filling should be done under controlled conditions to ensure that foundation failure does not occur during filling. The water test pressure is an integral part of the foundation design and should be agreed with a soil mechanics specialist.

All tank tests will be carried out to provide adequate measured load/settlement records.

The first tank in a new area will be the most critical and subsequent testing arrangements on other tanks should be adjusted in the light of the first test results where the tanks are on similar sub-soil conditions.

A minimum of four points on tanks under 25 m diameter and eight points on tanks over 25 m diameter should be marked around the base of the tank for subsequent levelling reference. A greater number of points may be required for large tanks and/or where a complex settlement pattern is expected. Before water is added to the tank, the levels at each reference point should be recorded. Permanent reference levels have to be established in locations unaffected by tank loading.

As a guide, when ground conditions are good and settlement is expected to be negligible, the tank may be half-filled with water as quickly as practicable, having regard to its size, the pumping facilities and water supply available. No further filling should proceed until levels have been taken and checked against the readings when empty to ensure that no uneven settlement is occurring in which case filling can proceed until the tank is three-quarters full, when level readings should be taken again. Provided the tank remains level with only slight settlement due to load, filling can then proceed until the tank is full, when level readings are again repeated. The full water load should be maintaind for 48 h and provided levels remain sensibly consistent, the tank can be offloaded prior to calibration for service. Provided this tank is satisfactory and subsequent tanks are founded similarly, the level readings at one-half and three-quarters capacity may be omitted for small tanks of less than 25 m diameter. On weak ground where significant settlements may be expected or where the initial factor of safety against slip failure is low, the rate of filling should be greatly reduced. Some guidance on the safe heights for initial filling and where pauses in filling are required may be deduced from the soil investigation and from piezometric monitoring of pore water pressures.

Typically, where settlements of over 300 mm may be expected, water should be added to the tank at about 0.6 m per day until about 3 m of water is stored. At such a head, filling should cease and levels at the reference points should be recorded daily. Daily reference point levels should be plotted on a timescale to follow the pattern of settlement.

When the daily rate of settlement begins to decrease, water should be added to the tank in decreasing increments of head when the settlement graph shows that the rate of settlement under each new increment of load is reducing. As the water load nears the full capacity of the tank, water should preferably be added after an early morning check of reference levels so that further readings can be taken during the day and the tank offloaded should the rate of settlement increase unduly. On very weak soils, these tests may extend over considerable periods and where such conditions apply, the tank builder should be advised so that adequate provisions can be made in his programme for the necessary testing and acceptance procedure.

Some guidance on safe heights for initial filling and where pauses are desirable may be deduced from the shear strength data and strata thicknesses of the underlying soil.

In carrying out such test procedures adequate arrangements should be made for the emergency disposal of water if off-loading became necessary. Discharge should be to a safe area, clear of all foundations and structures and such that no danger of erosion can occur.

Appendix B Recommendations for the design and application of insulation

B.1 General

This appendix is intended for new tanks but may also be used for existing tanks. While not attempting to specify in detail the insulation systems themselves, it is intended to provide a sound basis on which these systems can be specified and particularly to facilitate the provision of suitable mechanical supports for the insulation material, these supports to form an integral part of the tank fabrication. The recommendations cover storage tanks operating at temperatures above ambient and of a size where banding is unreliable and direct fixing to the tank is necessary.

In order that a correct choice may be made of type and method of providing the insulation attachments, it is emphasized that, where new tanks are concerned, early consideration of the need for insulation is essential so that the necessary provisions for it can be integrated with the tank design and erection programme. This consideration should also include the possible need for insulation of the tank roof.

On small tanks the problem of attaching the insulation securely is not serious but on tanks above 10 m to 15 m diameter problems due to wind loading, associated vacuum effects, differential thermal expansion and hydraulic pressure expansion do become serious. Bands longer than about 12 m are not recommended without special care in band design and there are instances of failure due to the inadequacy of such methods of securing insulation and cladding to the tank.

Wherever possible the insulation system should be secured by direct attachment to the tank. This can be achieved by sprayed-on insulation, by foaming in situ or by mechanical attachments to the tank. While welding of studs or steel members to small tanks may be satisfactory, welding on large tanks can materially affect the design and integrity of the construction but it is permissible when considered as part of the tank design. The use of adhesives is a possible alternative method of fastening attachments where welding cannot be permitted but is subject to temperature limitations and should only be carried out by specialists in this field.

The basis of all welded-on attachments should be to provide a series of points disposed circumferentially on the tank at a number of vertical intervals, on to which vertical and/or horizontal members may be fastened. The support structure and welded-on attachments should be designed so as to transmit back to the tank all the dead loads and superimposed wind loads expected to be experienced at the location concerned.

Design aspects which are not dealt with in this appendix should comply with the requirements in the main body of the text.

On existing tanks, careful consideration needs to be given in such cases to the safety aspects in providing the attachments in order to take account, where corrosion has taken place, of the corroded shell thickness and to provide an adequate safety margin in the design of the system as a whole.

The basic consideration necessary on methods to be employed to achieve acceptable insulation systems are set out below. These insulation systems suitable for large tanks include:

a) man-made mineral fibre or preformed foam block with cladding;

b) in situ foam behind cladding;

c) foam/cladding laminate sheets;

d) sprayed foam.

This standard recognizes that for a particular installation a proprietary system of insulation including fixing and weather protection may be suitable. If a proprietary system is offered, specific acceptance should be obtained, the element of the system that constitutes the mechanical support which forms part of the tank fabrication being clearly identified.

In this appendix, separate references are made to the tank designer, i.e, the organization responsible for carrying out the design of the tank, and the tank fabricator, i.e. the organization responsible for the erection of the tank, but it is recognized that this distinction is only necessary in the event that the two parties are not the same.

B.2 Design considerations

B.2.1 ***General***

The design of an insulation system, which incorporates the insulating material, its means of attachment to the tank and its means of weather protection, should take into account the following:

a) the product in the storage tank under its operating conditions;

b) the storage tank itself;

c) the insulation materials;

d) the mechanical support system associated with the insulation system;

e) the means whereby the insulation and its support system is enabled to withstand environmental conditions.

The insulation system is to be agreed between tank designer, insulation contractor and the purchaser.

The system including its mechanical supports and fastenings should be designed to withstand the mechanical and thermal stresses to which it will be subjected resulting from all known factors including those listed in **B.2.2** to **B.2.5** These factors should be assumed to occur simultaneously.

Because relatively large forces are involved in providing a secure system for the attachment of insulation to the outside of storage tanks, the mechanical support arrangements can be extensive and will frequently be attached to the outer face of the tank itself. The design of the attachment of the support system should be subject to careful scrutiny by the tank designer and he should ensure that a minimum of attachments are used.

Preliminary discussions with insulation contractors are often helpful in identifying suitable systems and the type of supporting arrangements likely to be necessary.

B.2.2 ***Dead load***

Dead loads result from the weight of all parts of the insulation system.

B.2.3 ***Wind loading***

In the design of the insulation system account is to be taken of the effect of wind loading using CP 3:Chapter 5-2 as a basis for estimating wind pressures. The parameters required for using CP 3, including the basic wind speed appropriate to the site and the factors S1, S2 and S3, should be agreed between the tank designer and the purchaser and this information given to the insulation contractor. Unless otherwise specified, the parameter S3 is to be based on a life of 25 years. At present CP 3 does not give pressure coefficients for the full range of shape factors that are of interest in large tank insulation and further data are required to include smaller height/diameter ratios, appropriate roof profiles and the effect of proximity where more than one tank is involved.

The tank designer should agree with the purchaser the basis on which the wind loading calculations are to be made.

B.2.4 ***Thermal expansion***

The possibility of relative thermal movement between the tank and the insulation system should be taken into account in the design. The purchaser will state the range of operating temperatures.

B.2.5 ***Movements due to hydrostatic pressure***

The pressure of the tank contents causes slight bulging which may account for an increase in tank diameter of the order 0.1 %, this may need to be taken into account in designing the insulation system and the actual value is to be provided by the tank designer.

B.3 Mechanical support arrangement

B.3.1 ***General***

The mechanical supports may be divided into the following.

a) *Primary mechanical supports,* where the members form part of the mechanical support system and are directly attached to the tank surface.

b) *Secondary mechanical supports,* where the members form part of the mechanical support system and are not directly attached to the tank but are fixed to the primary support members or to other secondary support members.

Suitable mechanical supports for the insulation system should be provided by one of the following means or a combination thereof.

1) Primary supports, welded to the tank, to which the insulation system is attached either directly or by secondary supports.

2) A structural frame that is substantially self-supporting.

3) Primary supports fixed to the tank by adhesive, to which the insulation system is attached.

Welding is the preferred method of attachment but may not always be possible especially where existing tanks are to be insulated. While in each case the system chosen is to be with the agreement of all parties concerned, the direct responsibilities will be as follows unless otherwise agreed.

i) In cases 1) and 3), the insulation contractor should agree with the tank designer the locations of the supports to which the insulation system is to be attached and the loads that will be transmitted to the tank and the basis on which his calculations have been made or other reference data he has used. If required, he should provide details of the calculations to be approved by the tank designer.

ii) In case 2) where an external structure or frame is intended, this will be regarded as part of the insulation system to be provided by the insulation contractor. The design and erection procedure should be agreed with the tank designer but will be the responsibility of the insulation contractor unless otherwise agreed.

The dimensions of the mechanical supports normal to the surface to which the insulation is to be attached should be an agreed size to suit the insulation thickness.

B.3.2 ***Supports attached by welding***

The primary mechanical supports will form part of the tank structure and the tank designer will be responsible for approving the material and the welding procedures. The tank fabricator will be responsible for fixing the primary supports to the tank surface. Welding of primary supports to the tank will be completed before hydraulic testing is carried out. The number of multiple-welded insulation support attachments to high tensile steel (minimum specified tensile strength 460 N/mm^2) shells should be minimized. In any case the centre-to-centre distance between them should not be less than 3 m.

All welds should be ground smooth and magnetic particle crack detected (see **11.15**). These supports should take one of the following forms.

a) Pads (not smaller than 100 mm square) with corners rounded to a radius not less than 12 mm, spaced not closer than 150 mm to any other weld and welded along horizontal edges only (see Figure 36).

b) Angles or plates welded on-edge to the tank having a circumferential length of not less than 100 mm at a spacing not closer than 150 mm to any other weld, welded along horizontal edges only (see Figure 37).

Materials for the primary supports are to be selected according to the requirements of this specification. In cases a) and b), secondary supports may be welded or attached to the pads, plates or cleats. In the case of circumferential angles, the welds should not be closer than 150 mm to other horizontal welds. The welding will be carried out by approved welders and the welding and non-destructive testing procedures should be agreed between the tank designer and the purchaser.

Plates welded on-edge or pads will be placed in horizontal rows at a suitable vertical pitch which will be, typically, 2 m to 3 m. Horizontal support angles, whether primary or secondary, should be of a minimum size 40 mm × 40 mm × 5 mm and of radial dimension compatible with the insulation system (see **B.8.1.3**). The spacing between adjacent members will not be more than ± 15 mm from the specified dimensions with the spacing between the highest and lowest members being not more than ± 25 mm from the specified dimensions. The outer leg of the member should be pointing downwards in order to shed water during construction.

B.3.3 ***External structural frame***

A structural frame suitably attached to the tank structure at the top and bottom may be used in certain circumstances. This may be in contact with the tank or external to the insulation.

B.3.4 ***Supports attached by adhesive***

B.3.4.1 *General.* If an adhesive system is used, the materials and procedure are to be such as to withstand the working conditions including both mechanical and thermal conditions. The surface of the tank in the vicinity of the fixing and the contact surface of the member to be fixed should be shot-blasted and the adhesive applied only to clean dry metal and strictly in accordance with the instructions of the adhesive manufacturer, account being taken of the suitability of the adhesive formulation for the ambient conditions, particularly temperature, at the time of application. Procedure, qualification and acceptance tests are to be carried out to the satisfaction of the purchaser.

B.3.4.2 *Procedure tests.*Tests will be carried out using the proposed procedure to demonstrate to the satisfaction of the purchaser that it is capable of providing 12 times the strength required as calculated from the wind loading and any other loading if applicable (see **B.2.2**). Such tests should include exposure for not less than 2 months at the temperature at which the surface of the tank will reach in service and temperature cycling if appropriate.

B.3.4.3 *Qualification tests.*Only trained personnel are to be used in making the adhesive joints and each individual to be employed on this work should carry out the qualification test within one month of commencement of adhesive joint preparation. Six joints will be prepared in the manner proposed for the contract and in the presence of such persons as may be agreed between the purchaser and the tank designer. When tested according to the agreed procedure the strength of these joints should exceed 12 times the minimum required strength.

B.3.4.4 *Acceptance tests.*Records are to be kept to permit identifications of supports attached with adhesive from each separate batch. A proof load will be applied equal to three times the calculated load. If more than 5 % of the batch has failed, the whole batch is to be removed and replaced.

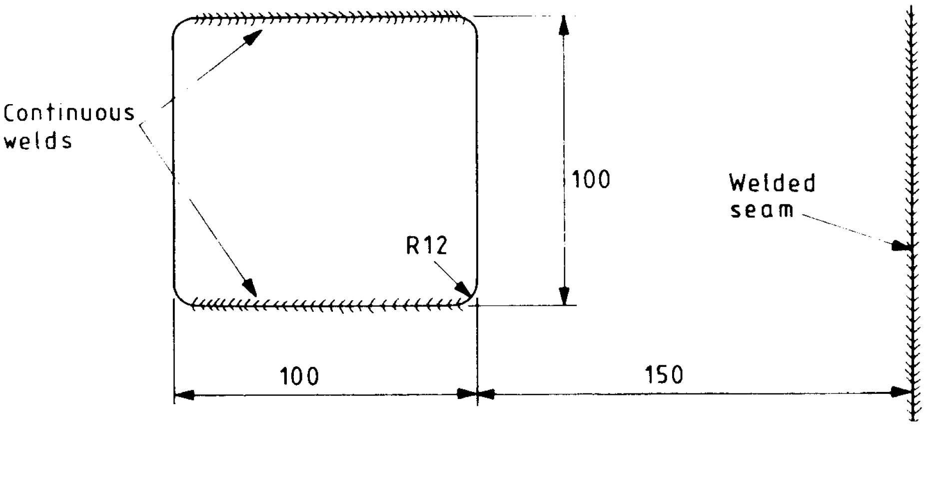
B.3.5 ***Secondary support members***

The design of secondary support members and their attachments to the primary support will be the responsibility of the insulation contractor who will obtain the agreement of the tank designer to the design and means of attachment. It should be made clear in enquiries to the insulation contractor whether or not he is to provide the material forming the secondary supports for which he is taking the responsibility. Holes made in any support member welded to the tank should be drilled, not punched, and if self-tapping screws are used, they should be not larger than 6 mm diameter.

B.3.6 ***Roof insulation***

Early consideration of the possible need for roof insulation is important. A roof construction of adequate stiffness is required with the slope everywhere adequate to permit satisfactory weather protection of the insulation.

In the case of tanks with an insulated shell, where the tank roofs are not insulated, calculations should be carried out to check the stresses in the roof supporting structure caused by the difference in temperature of the roof plates and the supporting structure, e.g. when cold rain falls on roof plates.



All dimensions are in millimetres.

Figure 36 — Pad supports [see **B.3.2** a)]

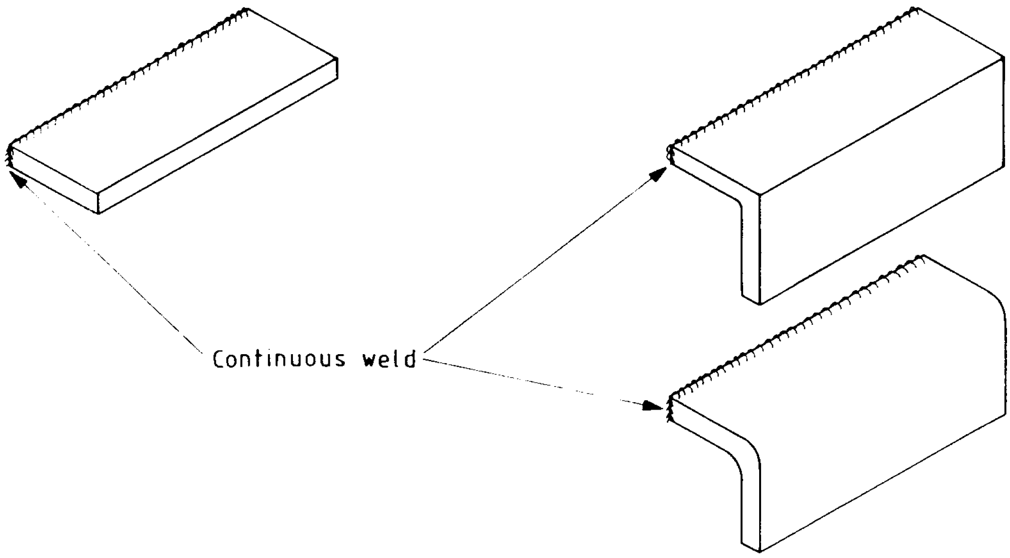


Figure 37 — Angle section and plate supports [see **B.3.2** b)]

B.4 Design details

B.4.1 *Nozzles and manholes*

Where nozzles and manholes are flanged, they will project a distance from the tank shell not less than the insulation thickness plus 1.5 times the bolt length unless otherwise agreed (see Figure 38). If a nozzle projects a greater distance from the tank, it is to be insulated (see **B.6.1**). Where adjacent nozzles are close together, they should be offset to ensure 50 mm minimum clearance between the insulated flanges. All nozzle and manhole connections requiring insulation are to be clearly indicated.

B.4.2 *Stairway connections*

The inner stringer of double-stringer staircases should be spaced away from the tank a distance sufficient to ensure not less than 75 mm between it and the outer face of the insulation system. Stairways with treads welded directly to the shell should not be used on insulated new tanks. With such stairways on existing tanks, a weather shield should be provided beneath the treads of dimensions to ensure adequate weather protection of the insulation.

B.4.3 ***Supports near wind girder***

Horizontal supports should be fitted not further than 300 mm below and 150 mm above wind girders. Intermediate stiffeners should also be included in the insulation of the shell unless the stiffening angles are welded on the inside of the tank shell.

B.4.4 ***Roof projection***

If the tank roof is designed to project beyond the tank shell, the projection should be not less than the thickness of the insulation system plus 50 mm. If the roof weather protection is provided as part of the insulation system, the overlap should similarly be not less than 50 mm beyond the thickness of the insulation on the tank shell. The over-hanging part of the roof should be completely included in the insulation. Details of this are to be agreed between the manufacturer and the insulation contractor.

B.4.5 ***Wind stiffening rings***

In certain circumstances it may be desirable to locate the wind stiffening rings on the inside of the tank shell (see **B.6.3**).

B.4.6 ***External shell wind girders and bottom-to-shell insulation***

External shell wind girders and bottom-to-shell insulation represent a discontinuity in the envelope of the tank and require detailed consideration by the insulation system designer in conjunction with the tank designer to avoid the following.

a) Unacceptable thermal gradients in the tank plate material due to part exposure.

b) Consideration of potential corrosion due to such areas forming a lodgement for corrosive fluids. Consideration should be given to enveloping all such structural elements with the insulation, particularly if the storage temperature is high, but each case is to be taken on its merits.

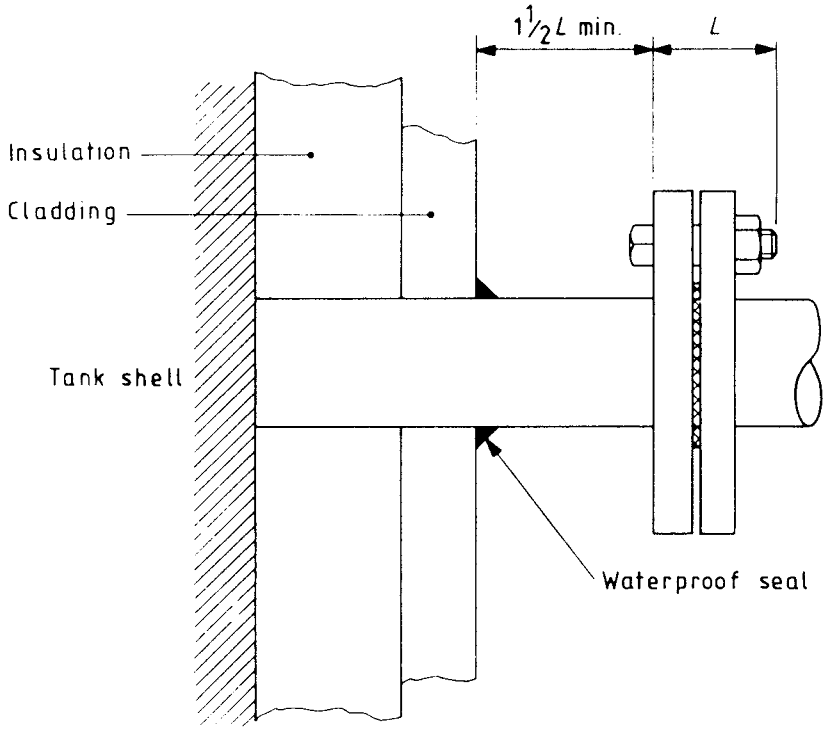


Figure 38 — Typical flanged nozzle or manhole (see **B.4.1** and **B.6.2**)

B.5 Corrosion protection

The presence of insulation prevents inspection of the tank surface and priming is therefore required before the insulation is applied. The tank shell and welded attachments should be dry, free from grease and loosely adhering particles and coated with a suitable primer, all to a specification agreed by the purchaser, if the roof is to be insulated, two coats of primer are recommended. If shop priming is employed, care should be taken to make good any defects in the priming caused during site fabrication.

The responsibility for this work is to be clearly determined at the time the tankage contract is let.

In the case of in situ spraying or foaming, the paint system should be such that it is compatible with the foam system and unaffected by any foaming reaction or in-service condition. Where foam insulation is used with fire retardant formulations, protection against the possibility of halogen-induced accelerated corrosion should be considered.

B.6 Insulation

B.6.1 ***General***

Insulation practice should be in accordance with BS 5970. Insulation thickness should be specified by the purchaser or designed to meet the purchaser's heat loss requirements. Unless the stresses produced are unacceptable, the insulation should terminate approximately 150 mm from the tank base to avoid corrosion and to allow inspection at the bottom of the tank (see Figure 39). Where the stresses are unacceptable, foamed glass slabs set in bitumen or other suitable adhesive may be used for insulation of the tank shell below the lowest horizontal support.

The shell insulation should fit closely under the roof overlap and be sealed against ingress of water (see Figure 40).

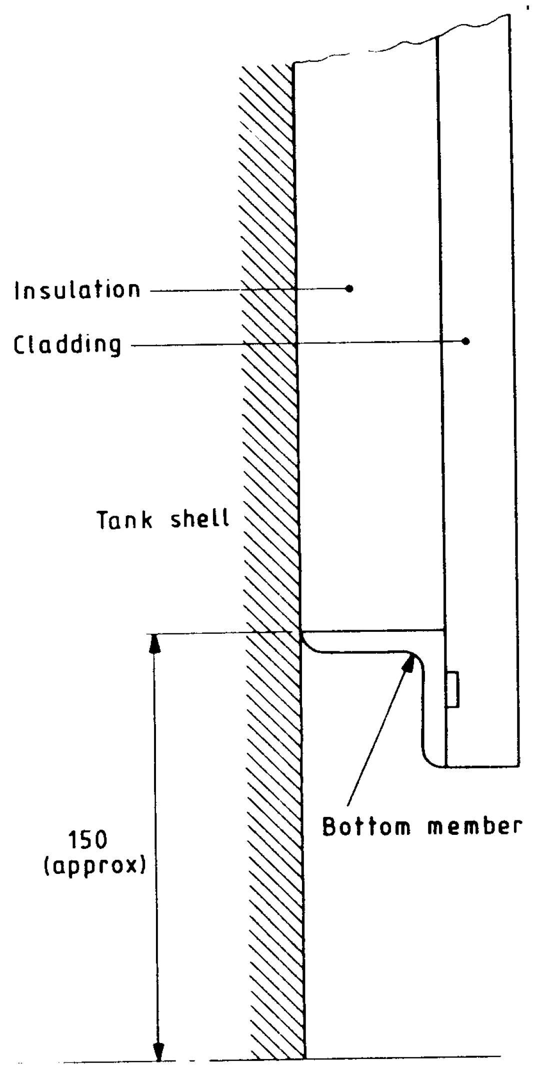
Special care should be taken where roof insulation is to be carried out to avoid corrosion (see **B.4.4**, **B.7.3** and **B.8.4**). When the roof is not insulated, a check should be made as to whether the thermal stresses in the roof supporting structure, caused by the difference in temperature between roof plates and supporting structure, are acceptable (see Figure 40).

B.6.2 ***Nozzle connections and manholes***

Where these project up to a distance equal to the sum of the insulation thickness plus depth of cladding profile plus 1.5 times the bolted length, they are to be insulated with the main shell/roof insulation (see Figure 38). Where the projection is in excess of the above, they will be insulated and finished prior to the application of insulation to the shell/roof (see Figure 41).

B.6.3 ***Wind stiffening rings***

The wind stiffening rings and their associated supports should be enclosed by the shell insulation to minimize the temperature difference; Figure 42 shows a typical construction local to a wind stiffening ring.



Dimension is in millimetres.

Figure 39 — Typical arrangement showing termination of insulation adjacent to the tank bottom (see **B.6**)

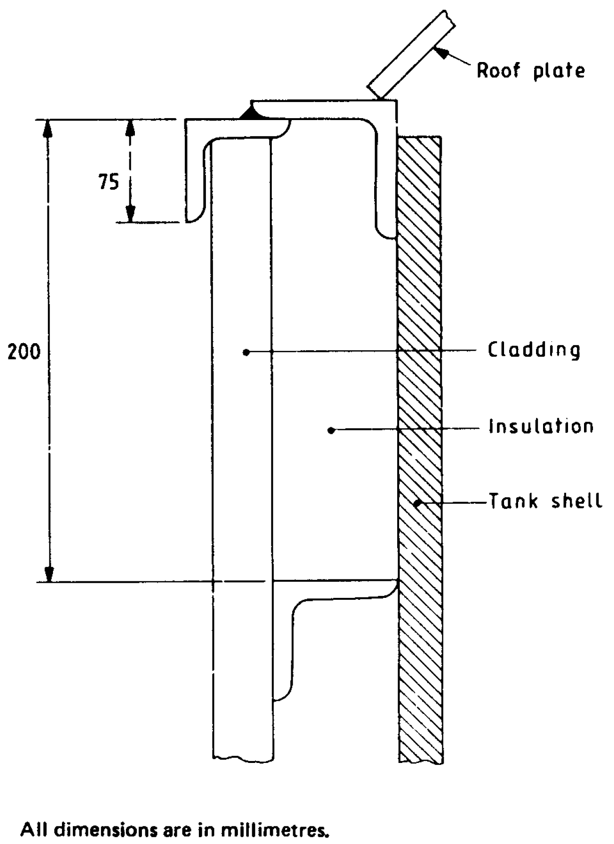


Figure 40 — Typical arrangement with insulation attached to the shell only (see **B.6**)

B.7 Cladding

B.7.1 ***General***

Cladding is a feature common to most insulation systems. The effectiveness of the insulation depends particularly on the care applied in the design and installation of the cladding. The type and quality of cladding should be selected bearing in mind environmental conditions on either side.

It is essential that all cladding be kept clean, free from grease, free from corrosion and dry on the inner surface prior to erection and until the installation is complete and all joints are well sealed.

B.7.2 ***Side-wall cladding***

Care should be taken to prevent direct contact between stairway supports and cladding. Cut-outs in cladding for stairway supports should be sealed with mastic to prevent ingress of water. Sealant is not normally considered necessary for vertical or horizontal joints in the cladding.

The tank side-wall cladding should be troughed aluminium or galvanized steel sheet attached to the support members. The minimum depth of trough is to be 25 m. Corrugated sheet having sinusoidal profiles should receive special attention in view of the need to avoid the ingress of water and to ensure adequate fixing. The minimum thickness of sheet should be:

a) 0.9 mm for aluminium;

b) 0.7 mm for galvanized or plastics-coated steel.

Galvanized steel sheet will be grade Z2, coating type H1 complying with BS 2989.

Aluminium sheet should be to BS 1470 – BS 3103, BS 4300/6 – BS 3105 or BS 1470 – BS 5251 of grade H4 or harder or be of the grades specified in BS 4868.

In any horizontal ring, adjacent sheets should have a minimum overlap of one trough profile and be secured with bulb-type blind pop-rivets at not greater than 100 mm pitch. The rivets should be of material compatible with the cladding and such as to secure the overlap to accommodate the maximum design wind-suction.

Each horizontal ring of cladding should overlap the lower horizontal ring by a minimum of 75 mm and be secured with bulb-type blind pop-rivets at a distance not less than 25 mm from the edges of the sheets.

Sheets should be secured to support members using fastenings designed to accommodate the agreed wind loading and tank movements due to thermal expansion and hydrostatic pressure.

B.7.3 ***Roof cladding***

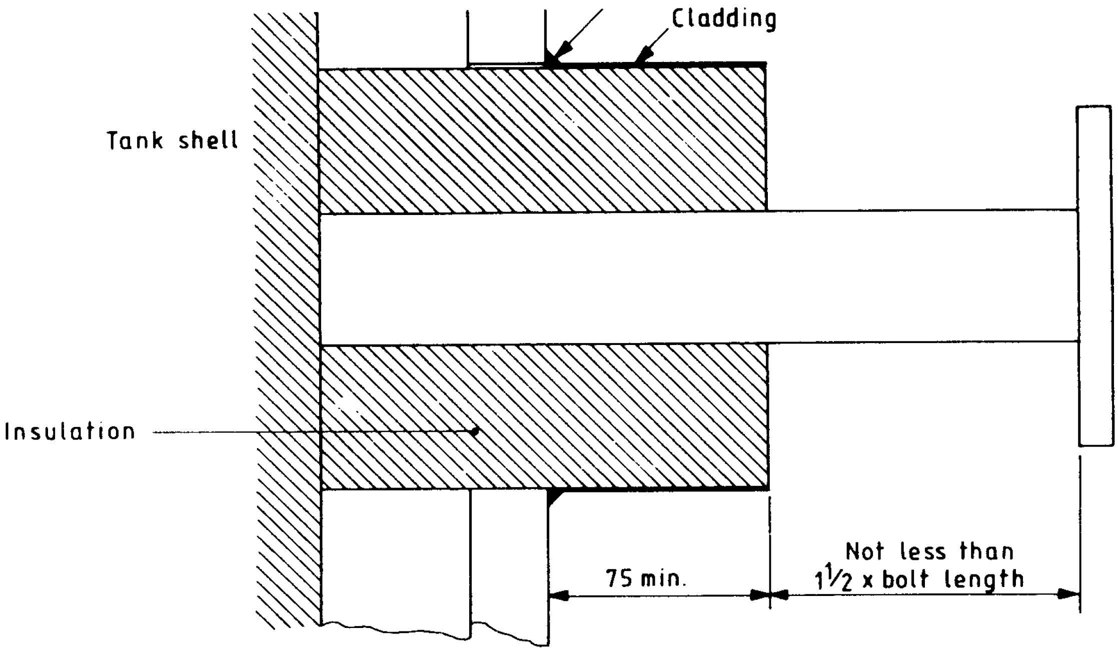
Metal cladding for the tank roof should be plain or embossed and the minimum thickness should be:

a) 1.2 mm for aluminium;

b) 0.9 mm for galvanized or plastics-coated steel.

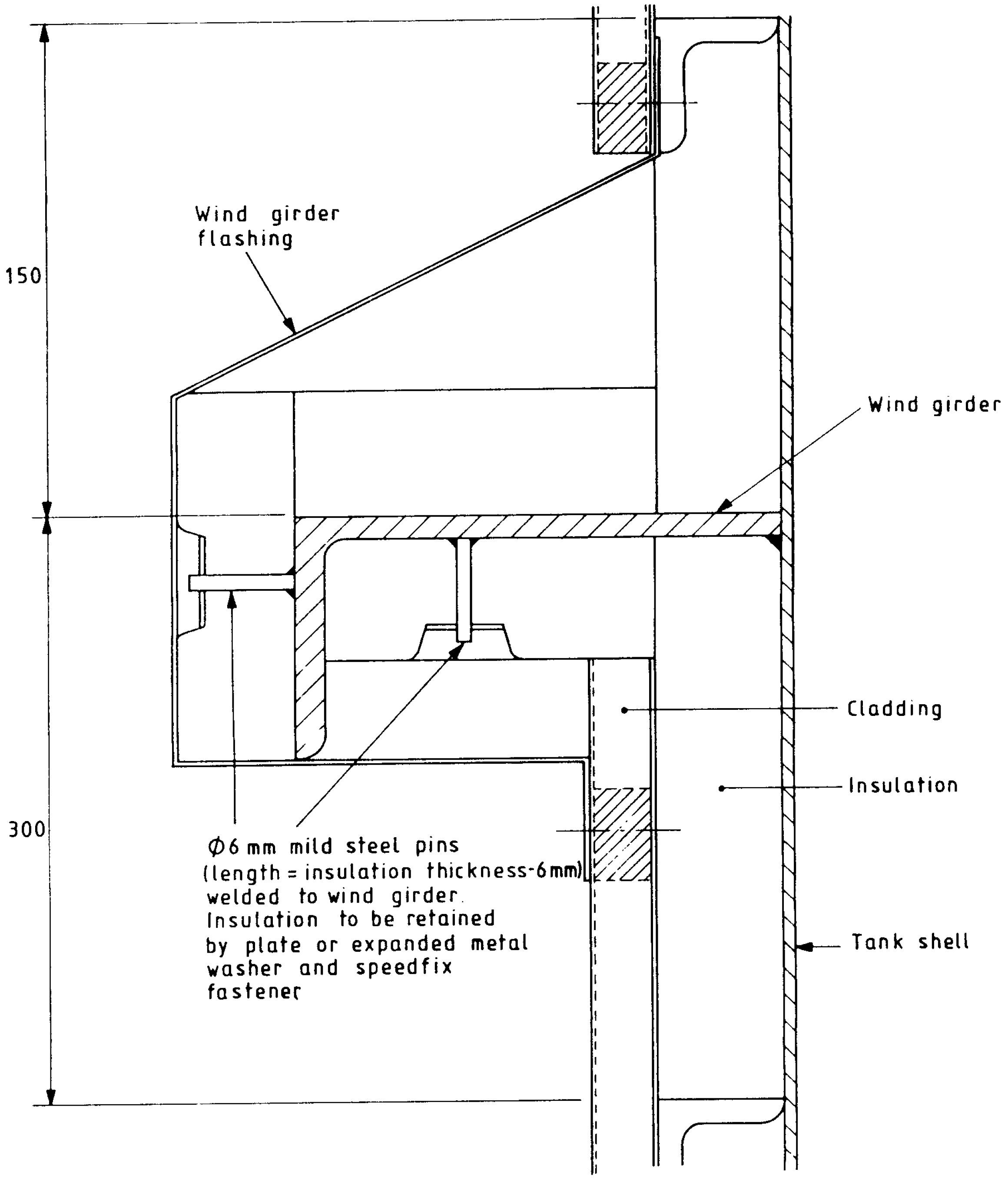
All overlaps in the cladding are to be not less than 100 mm and be so arranged as to shed water. All joints should contain a continuous strip of a sealant approved by the purchaser and be secured by bulb-type blind pop-rivets of a material compatible with the cladding. The pop-rivets should be at a maximum pitch of 75 mm.

Consideration should be given to properly draining rainwater over the edge of the roof so that it does not affect the integrity of the insulation system. (See Figure 40.)



All dimensions are in millimetres.

Figure 41 — Typical flanged nozzle or manhole with additional branch insulation (see **B.6.2**)



All dimensions are in millimetres.

Figure 42 — Typical construction of insulation local to wind stiffening ring (see **B.6.3**)

B.8 Securing insulation materials

B.8.1 *Slab or block insulation with metal cladding*

B.8.1.1 *Bonded man-made mineral fibre with metal cladding.* The insulation should consist of bonded mineral wool complying with BS 3958-5, the bulk density being not less than 48 kg/m^3.

The insulation material should be supported on the horizontal support members and held in place with 1 mm (minimum) galvanized tie wires for use with galvanized steel cladding and 0.5 mm (minimum) stainless steel wire for use with aluminium cladding or plastics-coated steel cladding. The insulation slabs should be fitted tightly between the horizontal support members with all edges closely butted and vertical joints offset from those in adjacent courses. The tie wires should be at a pitch not greater than 450 mm with a minimum of two tie wires per insulation slab.

B.8.1.2 *Other slab or block insulation with metal cladding.* Preformed slabs of polyurethane or polyisocyanurate may be used on the tank sides as an alternative to mineral wool, the method of fixing being similar to that described for mineral wool slabs (see **B.8.1.1**) or by adhesives suitable for the operating temperature.

For certain circumstances foamed glass blocks may be required. Where this material is used, the blocks should be held in place with 20 mm × 0.8 mm bands of approved material at centres not exceeding 450 mm. The bands should be secured to vertical tie bars fitted to the horizontal support members at centres not exceeding 12 m. Alternatively, adhesives suitable for the operating temperature may be used.

B.8.1.3 *Horizontal supports.* The horizontal supports will have a radial width adequate for support of the insulation and agreed with the insulation contractor.

B.8.2 *In situ foam behind metal cladding*

The type of foam and its physical and thermal properties are to be agreed between the insulation contractor, the tank designer and the purchaser. The cladding should comply with **B.7.2** or **B.7.3** The cladding may be supported as recommended in **B.7.2** or may be spaced from the tank using foamed blocks, stuck to the side-wall, of agreed type and size and of thickness equal to the minimum insulation thickness. Provision will be made, in the latter system, to restrain the cladding against distortion and movement due to pressure exerted by the foaming operation. Due regard should be taken in this latter system of the attachment of the insulation to the tank shell and cladding, to ensure adequate resistance to wind loads. Approved flashings or other means of weather protection should be provided where metal connections for walkways, etc. penetrate the insulation. All pipe connections should be insulated prior to fitting the cladding. The insulation at the roof edge is to terminate as shown in Figure 40.

The sequence of the cladding and foaming procedure, the method of injecting the foam and the foaming pattern are to be approved by the tank designer and the purchaser.

The insulation contractor will define the weather and substrate temperature limits necessary for satisfactory foaming.

Means should be agreed between the insulation contractor, the tank designer and the purchaser for establishing and checking the satisfactory quality of the foam.

B.8.3 *Sprayed foam*

The type of foam and its physical and thermal properties should be agreed between the insulation contractor, the tank designer and the purchaser.

The insulation contractor will define the weather and substrate temperature limits necessary for satisfactory spraying.

The thickness of the sprayed foam is not to be less than the nominal design thickness. The standard of finish of the sprayed foam will be agreed with the purchaser and the insulation contractor and samples of foam of the agreed appearance prepared and retained for reference. Means should be agreed between the insulation contractor, the tank designer and the purchaser for establishing and checking the satisfactory quality of the foam.

If a weatherproof finish is required, this should be applied over the foam insulation preferably by spraying after the foam is fully cured. The weatherproof finish should be applied in two coats of different colours. Where extra resistance to mechanical damage and/or bird attack is required, an agreed reinforcing medium should be applied between the two layers of the finish. The weatherproof finish will have a class 1 surface spread-of-flame rating when tested to BS 476-7. The insulation contractor is to agree suitable means for weather protecting the foam at the top edge of the tank.

The tank should be left uninsulated for a distance of approximately 150 mm from the base.

B.8.4 ***Roofs***

Where mineral wool and metal cladding form the insulation, the mechanical support system should comply with **B.3.5** and **B.3.6** and be of upstand not less than the thickness of the insulation and not greater than this thickness plus 5 mm. Metal cladding is to be as described in **B.8.2** and be fixed to the support system to withstand wind loading and wind induced vibrations. The fastening will be compatible with the cladding.

Additional reinforcement of the insulation system may be necessary where access may be required.

It may be convenient to apply foam insulation to the roof, either sprayed or foamed in situ, even if a mineral wool or other system is specified for the tank sides.

B.9 Fire hazard

Possible fire hazards exist during construction and operation when organic plastics foam insulation is used. Although some materials and formulations are more resistant to fire than others, they are nevertheless still combustible and may not necessarily alleviate a fire hazard.

Appendix C Standard diameters for vertical cylindrical tanks

The standard range of diameters is based on the application of the standard lengths for shell plates given in Table 8.

Table 8 — Standard lengths for shell plates

Tank diameter	Shell plate length
m	
3	1.5 π
4 to 10	2.0 π
12.5 to 30	2.5 π
33 to 114	3.0 π

Table 9 gives the capacities for the standard range of diameters.

These standard plate lengths are selected in accordance with plate lengths generally used in Europe.

The heights have not been standardized and Table 9 shows capacities for every metre of tank height.

For a given tank height the manufacturer may choose the number of courses and the plate widths to obtain the most economical solution.

It is strongly recommended that the standard diameter given in Table 9 should be used. The standardization will reduce the possibility of errors in design, fabrication and erection as well as the time required for approval of design drawings by purchasers and authorities.

Table 9 — Nominal capacities of standard vertical cylindrical tanks

Height	Tank diameter (m)																
	3	4	6	8	10	12.5	15	17.5	20	22.5	25	27.5	30	33	36	39	42
	Nominal capacities																
m	m^3	m^3	m^3	m^3	m^3	m^3	m^3	m^3	m^3	m^3	m^3	m^3	m^3	m^3	m^3	m^3	m^3
1	7	12	28	50	78	122	176	240	314	397	490	593	706	855	1 017	1 194	1 385
2	14	25	56	100	157	245	353	481	628	795	981	1 187	1 413	1 710	2 035	2 389	2 770
3	21	37	84	150	235	358	530	721	942	1192	1 472	1 781	2 120	2 565	3 053	3 583	4 156
4	28	50	113	201	314	490	706	962	1256	1590	1963	2 375	2 827	3 421	4 071	4 778	5 541
5	35	62	141	251	392	613	883	1202	1570	1988	2 454	2 969	3 534	4 276	5 089	5 972	6 927
6	42	75	169	301	471	736	1 060	1443	1884	2385	2 945	3 563	4 241	5 131	6 107	7 167	8 312
7		87	197	351	549	859	1 237	1683	2199	2783	3 436	4 157	4 948	5 987	7 125	8 362	9 698
8		100	226	402	628	981	1 413	1924	2513	3180	3 926	4 751	5 654	6 842	8 142	9 556	11 083
9			254	452	706	1 104	1 590	2164	2827	3578	4 417	5 345	6 361	7 697	9 160	10 751	12 468
10			282	502	785	1 227	1 767	2405	3141	3976	4 908	5 939	7 068	8 552	10 178	11 945	13 854
11				552	863	1 349	1 943	2645	3455	4373	5 399	6 533	7 775	9 408	11 196	13 140	15 239
12				603	942	1 472	2 120	2886	3769	4771	5 890	7 127	8 482	10 263	12 214	14 335	16 625
13					1 021	1 595	2 297	3126	4084	5168	6 381	7 721	9 189	11 118	13 232	15 529	18 010
14					1 099	1 718	2 474	3367	4398	5566	6 872	8 315	9 896	11 974	14 250	16 724	19 396
15					1 178	1 840	2 650	3607	4712	5964	7 363	8 909	10 602	12 829	15 268	17 918	20 781
16					1 256	1 963	2 827	3848	5026	6361	7 853	9 503	11 309	13 684	16 285	19 113	22 167
17						2 086	3 004	4088	5340	6759	8 344	10 097	12 016	14 540	17 303	20 308	23 552
18						2 208	3 180	4329	5654	7156	8 835	10 691	12 723	15 395	18 321	21 502	24 937
19						2 331	3 357	4570	5969	7554	9 326	11 285	13 430	16 250	19 339	22 697	26 323
20						2 454	3 534	4810	6283	7952	9 817	11 879	14 137	17 105	20 357	23 891	27 708
21							3 711	5051	6597	8349	10 308	12 473	14 844	17 961	21375	25 086	29 094
22							3 887	5291	6911	8747	10 799	13 067	15 550	18 816	22 393	26 280	30 479
23							4 064	5532	7225	9144	11 290	13 661	16 257	19 671	23 411	27 475	31 865
24							4 241	5772	7539	9542	11 780	14 254	16 964	20 527	24 428	28 670	33 250
25							4 417	6013	7853	9940	12 271	14 848	17 671	21 382	25 446	29 864	34 636

Table 9 — Nominal capacities of standard vertical cylindrical tanks

Height	Tank diameter (m)														
	45	**48**	**51**	**54**	**57**	**60**	**66**	**72**	**78**	**84**	**90**	**96**	**102**	**108**	**114**
	Nominal capacities														
m	m^3	m^3	m^3	m^3	m^3	m^3	m^3	m^3	m^3	m^3	m^3	m^3	m^3	m^3	m^3
1	1 590	1 809	2 042	2 290	2 551	2 827	3 421	4 071	4 778	5 541	6 361	7 238	8 171	9 150	10 202
2	3 180	3 619	4 085	4 580	5 103	5 654	6 842	8 142	9 556	11 083	12 723	14 476	16 342	10 312	20 404
3	4 771	5 428	6 128	6 870	7 655	8 482	10 263	12 214	14 335	16 625	19 085	21 714	24 513	28 468	30 606
4	6 361	7 238	8 171	9 160	10 207	11 309	13 684	16 285	19 113	22 167	25 446	28 952	32 685	36 624	40 808
5	7 952	9 047	1 0214	11 451	12 758	14 137	17 105	20 357	23 891	27 708	31 808	36 191	40 856	45 780	51 010
6	9 542	10 857	12 256	13 741	15 310	16 964	20 527	24 428	28 670	33 250	38 170	43 429	49 027	54 936	61 212
7	11 133	12 666	14 299	16 031	17 862	19 792	23 948	28 500	33 448	38 792	44 532	50 667	57 198	63 092	71 414
8	12 723	14 476	16 342	18 321	20 414	22 619	27 369	32 571	38 226	44 334	50 893	57 905	65 370	73 240	81 616
9	14 313	16 285	18 385	20 611	22 965	25 446	30 790	36 643	43 005	49 875	57 255	65 143	73 541	82 404	91 818
10	15 904	18 095	20 428	22 902	25 517	28 274	34 211	40 714	47 783	55 417	63 617	72 382	81 712	91 560	102 020
11	17 494	19 905	22 470	25 192	28 069	31 101	37 633	44 786	52 561	60 959	69 978	79 620	89 883	100 716	112 222
12	19 085	21 714	24 513	27 482	30 621	33 929	41 054	48 857	57 340	66 501	76 340	86 858	98 055	109 872	122 424
13	20 675	23 524	26 556	29 772	33 172	36 756	44 475	52 929	62 118	72 042	82 702	94 096	106 226	119 028	132 626
14	22 266	25 333	28 599	32 063	35 724	39 584	47 896	57 000	66 896	77 584	89 064	101 335	114 397	128 184	142 828
15	23 856	27 143	30 642	34 353	38 276	42 411	51 317	61 072	71 675	83 126	95 425	108 573	122 569	137 340	153 030
16	25 446	28 952	32 685	36 643	40 828	45 238	54 739	65 143	76 453	88 668	101 787	115 811	130 740	146 496	163 232
17	27 037	30 762	34 727	38 933	43 379	48 066	58 160	69 215	81 232	94 209	108 149	123 049	138 911	155 662	173 434
18	28 627	32 571	36 770	41 223	45 931	50 893	61 581	73 286	86 010	99 751	114 510	130 287	147 082	164 808	183 636
19	30 218	34 381	38 813	43 514	48 483	53 721	65 002	77 358	90 788	10 5293	12 0872	13 7526	15 5254	17 3964	
20	31 808	36 191	40 856	45 804	51 035	56 548	68 423	81 429	95 567	110 835	127 234	144 764	163 425		
21	33 399	38 000	42 899	48 094	53 586	59 376	71 844	85 501	100 345	116 377	133 596	152 002	171 596		
22	34 989	39 810	44 941	50 384	56 138	62 203	75 266	89 572	105 123	121 918	139 957	159 240			
23	36 579	41 619	46 984	52 675	58 690	65 030	78 687	93 644	109 902	127 460	146 319	166 479			
24	38 170	43 429	49 027	54 965	61 242	67 856	82 108	97 715	114 680	133 002					
25	39 760	45 238	51 070	57 255	63 793	70 685	85 529	101 787	119 458	138 544					

Appendix D List of symbols

		Units
A	Roof compression area	mm^2
B, B_1, B_2, B_3	Weld details—dimensions	mm
D	Tank shell diameter (nominal)	m
E	Young's modulus	N/mm^2
$F, F1, F2$	Weld details — dimensions	mm
Fa	Maximum allowable longitudinal compressive stress in the shell	N/mm^2
G_1, G_2	Lateral force coefficients given as a ratio of the acceleration of gravity	—
H	Tank shell height	m
H_e, H_E, H_P	Shell heights for stability calculations	m
H_L	Total height of tank shell	m
H_T	Maximum filling height of tank	m
J	Site amplification factor	—
K	Factor for stability calculations	—
K_s	Factor for seismic calculations	—
L	Shell branch length	mm
M	Overturning moment	kN·m
P_e	External roof loading	kN/m^2
R	Tank shell radius	m
R_1	Radius of curvature of roof	m
R_{eb}, R_{es}	Minimum specified yield strength	N/mm^2
S	Allowable design stress	N/mm^2
S_c	Allowable compressive stress	N/mm^2
T	Total weight of shell (**F.4.1** c) refers)	kg
T_1	Weight of effective mass of tank contents	kg
T_2	Weight of effective mass of first mode sloshing contents	kg
T_r	Total weight of tank roof	kg
T_s	Natural period of first mode sloshing	s
T_t	Total weight of tank shell	kg
T_T	Total weight of tank contents	kg
V_w	Design wind speed	m/s
W_c	Effective shell length for compression area	mm
W_h	Effective roof length for compression area	mm
X_1, X_2	Height to centroid	m
X_s	Height to centre of gravity	m
Z	Section modulus	cm^3
b	Wind girder dimension	mm

		Units
c	Corrosion allowance	mm
d	Diameter of hole in shell plate	mm
d_n	Outside diameter of nozzle body	mm
d_o	Outside diameter of reinforcing plate or insert plate	mm
d_r	Diameter of hole in roof plate	mm
e	Weld detail—dimensions	mm
g, g_1, g_2	Weld details—dimensions	mm
h	Height of each shell course	m
h_n	Height of roof nozzle	mm
J	Stress concentration factor	—
p	Design pressure	mbar
r	Weld dimension	mm
r_o, r_i, r_m	Outside, inside, and mean radii respectively for branch bodies	mm
s_1, s_2	Weld details—dimensions	mm
t	Shell plate thickness	mm
t_{min}	Top course shell plate thickness	mm
t_a	Angle stiffener thickness	mm
t_b	Tank bottom plate thickness	mm
t_{ba}	Thickness of bottom plate under the shell	mm
t_{br}	Bottom reinforcing plate thickness	mm
t_{bs}	Bottom course shell plate thickness	mm
t_c	Reinforcing plate thickness	mm
t_f	Flange and cover plate thickness	mm
t_i	Insert plate thickness	mm
t_p	Nozzle body thickness	mm
t_r	Roof plate thickness	mm
v_a	Design vacuum	mbar
W	Design liquid density	g/ml
W_b	Maximum longitudinal shell compression force	kN/m
W_L	Maximum force of tank contents	kN/m
W_s	The maximum density	g/ml
W_t	Maximum force	kN/m
Y	Replacement factor	—
α	Weld detail dimension	degrees
η	Joint efficiency factor	—
θ	Slope of roof	degrees
ϕ	A weld imperfection diameter	mm

Appendix E Recommendations for internal floating covers

[not intended for installation in pressure tanks (see **2.1**)]

E.1 General

E.1.1 The floating covers detailed in this appendix consist of an internal floating deck protected by a fixed-type roof which, while permitting the cover to operate up and down, prevents the ingress of rainwater, sand or snow.

Floating covers are also known as floating screens, floating blankets or floating decks.

E.1.2 Floating covers in fixed-roof tanks are normally used for the following applications; the order is not an indication of their relative importance.

a) Reduction of breathing and filling losses.

b) Reduction of air pollution.

c) Reduction of ingress of rainwater and sand into the product.

d) As an alternative to floating roofs in open-top tanks, in localities where excessive snow may be experienced.

e) To reduce the hazards of static ignition associated with highly charged liquid surfaces.

E.2 Types of cover

E.2.1 The more common types of cover fall into one of four categories briefly described as follows.

a) Rigid preformed polyurethane foam sections sandwiched between aluminium foil and fitted together with a simple connecting device.

b) Glass reinforced plastics panels superimposed on a flotation structure. The panels are bolted together to form a continuous covering over the entire liquid surface.

c) Aluminium sheeting, superimposed on a flotation structure or aluminium floats for buoyancy. The sheeting sections are joined together to form a continuous covering over the entire liquid surface.

d) A shallow steel pan designed to float over the entire liquid surface of the tank.

E.2.2 The design should not allow the contents to flow on to the cover.

E.2.3 The cover should be designed to support at least 3 men (300 kg over 3 m^2) anywhere over the surface of the cover in the floating (water testing only) and supported condition. This recommendation is included for inspection and maintenance purposes.

E.3 Materials

E.3.1 The purchaser should specify the liquid to be contained, indicating any special properties which may affect materials.

E.3.2 Materials should be compatible with the product contained. If dissimilar materials are used, the possibility of accelerated corrosion due to inter-reaction should be considered.

E.3.3 Sealing materials used to make joints in panels or sections should be compatible with the product contained.

E.3.4 Edge seal material should be highly resistant to abrasion and to any aromatic content specified by the purchaser. It should also be sufficiently flexible to take up irregularities in the tank shell.

E.4 Mountings

E.4.1 ***Ladders***

Access ladders from the fixed roof to the floating cover are not recommended. Access should be by way of the shell and cover manholes after the tank has been emptied and gas-freed (see **E.4.4.1** and **E.4.5**).

E.4.2 ***Cover drains***

Primary or emergency drains will not normally be required since the floating cover is not exposed to the elements. However, condensation can occur in the air space between the cover and the fixed roof and this may collect on the cover. Spillage of product on to the cover may also occur, and consideration should be given to the provision of a drain where such problems are anticipated. Simple drains which allow drainage directly into the product may be possible for some cover designs, but for single-deck pan-type covers only steel pipe or hose drains, having outlets through the shell, can be considered.

E.4.3 ***Vents***

E.4.3.1 *Floating cover*. The purchaser should specify the maximum liquid filling and withdrawal rates. Suitable vents or bleeder valves should be provided to prevent overstressing of the cover deck and seal membrane and should be adequate to evacuate air and gases from underneath the cover during initial filling and should also be adequate to allow air and gas to pass the cover, when the liquid is being withdrawn with the cover resting on its support legs.

E.4.3.2 *Tank shell*. Circulation vents should be provided in the tank shell, located clear of the seal when the cover is at its highest position. The maximum spacing should be 10 m, but in no case should there be less than four equally spaced vents. The total open area of these vents should be not less than 0.06 m^2 per metre of tank diameter.

E.4.3.3 *Fixed roof*. An open vent should be provided at the highest point of the fixed roof. It should have a weather cover and a minimum open area of 0.03 m^2.

E.4.3.4 *Protection*. Unless otherwise specified by the purchaser, vents should be provided with coarse mesh (minimum openings 6 mm × 6 mm square) to prevent the ingress of birds or animals.

E.4.4 ***Low level supports***

E.4.4.1 The cover should be supported at a low level to be specified by the purchaser. The manufacturer should ensure that all internal appurtenances such as side entry mixers, piping, inlet and outlet connections, etc. are clear of the cover in the low position. Supports fixed to the cover or the tank bottom may be used. The supports, attachments and tank bottom should be designed to support a live load of 0.4 kN/m^2.

If the load on a support exceeds 2.5 kN, steel pads or other means should be used to distribute the load on the tank bottom. Pads should be continuously welded to the tank bottom to prevent corrosion under the pads. Supports fabricated from pipe should be provided with a notch at the bottom for drainage.

E.4.4.2 On the underside of the deck plates of mild steel covers, where flexure is anticipated adjacent to cover supports or other relatively rigid members, full fillet welds not less than 50 mm long at 250 mm centres should be used on lap welds within 300 mm of such rigid supports or members.

E.4.5 ***Manholes***

At least one manhole, not less than 600 mm i.d., should be provided in the cover for access and ventilation purposes when the cover is on its supports and the tank is empty. The manhole should be designed to be opened from the underside of the cover. Loose covers may be used but the height of the manhole neck should be such as to prevent the contents flowing on to the cover.

E.4.6 ***Centralizing and anti-rotation devices***

Suitable arrangements should be made to maintain the cover in a central position and to prevent its rotation. The peripheral seal may be considered to act as a centralizing device and the roof support columns can be used as an anti-rotation device except where only a single central column is used.

E.4.7 ***Seals***

E.4.7.1 *Peripheral seals*. The clearance between the periphery of the cover and the tank shell should be fitted with a flexible seal and provide a reasonably close fit to the shell surface. The manufacturer should specify the maximum inward and outward movement of which the seal is capable.

E.4.7.2 *Cover penetrations*. Where fixed-roof support columns, anti-rotation devices or other appurtenances pass through the cover, seals should be provided to ensure a reasonably close fit, taking into account horizontal and vertical movements of the cover.

E.4.8 ***Gauging and sampling devices***

The fixed roof and the floating cover should each be provided with gauging and sampling devices designed to comply with the requirements of the purchaser.

E.4.9 ***Antistatic cables***

E.4.9.1 All covers should be electrically conductive. For non-metallic covers, antistatic materials should be used or, when agreed between the purchaser and the manufacturer, metallic strips bonded to the cover may be used as an alternative.

E.4.9.2 When peripheral seals with a high electrical resistance are used, e.g. non-metallic seals, flexible multistrand antistatic cables should be fitted between the cover and the tank shell to provide an electrical bond.

A minimum of two cables should be provided on tanks up to 20 m diameter and a minimum of four for larger diameter tanks.

E.4.10 ***High-liquid level alarms***

It is recommended that a high-level alarm be fitted which will automatically warn the operator of the tank overfilling or the cover fouling an obstruction, e.g. fixed-roof structure.

E.5 Fabrication

E.5.1 ***General***

Good workmanship and finish should be obtained throughout and all work subjected to the closest inspection by the manufacturer, even if the purchaser waives any part of his inspection.

E.5.2 ***Mild steel covers***

The fabrication of mild steel covers should comply with the minimum applicable requirements specified in clauses **13** and **14**.

E.5.3 ***Non-metallic components***

Components of covers, fabricated from non-metallic materials, should be provided with edges within tolerances which will ensure accurate and tight erection.

E.5.4 ***Workshop assembly***

If specified by the purchaser in the order, the assembly or part thereof should be laid out in the works for inspection.

E.5.5 ***Erection marks, packaging and shipping***

Erection marks, packaging and shipping should comply with this standard.

E.6 Erection

E.6.1 ***Rectification of damage to materials***

Any damaged material should be rectified by the contractor prior to erection, to the satisfaction of the purchaser.

E.6.2 ***Method of erection***

The method of erection for the floating cover should be submitted by the manufacturer or contractor for the approval of the purchaser, if such approval has not already been given in writing by the purchaser.

E.6.3 ***Circularity***

In the construction of the floating cover, every care should be taken to minimize distortion or lack of circularity due to welding or other reasons. The clearance between the periphery of the cover and the tank shell should be uniform and comply with the dimensional requirements specified for the seal (see **E.4.7.1**).

E.7 Testing

E.7.1 Where applicable, before a floating cover is put into operation, it should be carefully tested for liquid tightness. Lap-welded joints in mild steel covers may be tested by the vacuum box method or by the use of high penetrating oil.

E.7.2 On completion, the tank should be filled with water, to check that the cover and seals travel freely to the full operating height and that the cover is free from leaks.

E.7.3 Manholes in the fixed roof should be kept closed during testing in wet weather, since any ingress of rainwater might lead to misleading conclusions on water-tightness.

E.7.4 Any damp spot on the cover should be taken as an indication of a possible leak.

Time may be necessary for leaks to become evident and checks should therefore be made at frequent intervals, particularly during the first metre of filling.

E.7.5 All leaks detected during testing should be rectified to the satisfaction of the purchaser or his representative.

E.8 Operation

E.8.1 ***Access to the cover***

During operation, no access to the tank and floating cover should be permitted, and the tank and cover should be cleaned and gas-freed before access is permitted for maintenance purposes. It is recommended that this is indicated near the tank manholes.

E.8.2 ***Periodic inspection***

The cover should be inspected for leaks, when in the top position, from a suitable manhole in the fixed roof. It is recommended that this inspection be carried out during the first filling and subsequently at three-monthly intervals. It is also recommended that, where fitted, the antistatic cables be examined to ensure that the electrical bond between the floating cover and the tank shell is intact (see **E.4.9.2**).

E.8.3 ***Use of side entry mixers***

Side entry mixers should be allowed to operate only when the floating cover is at a level where the normal functioning of the cover will not be affected.

Appendix F Recommendations for the design of venting systems

F.1 General

This appendix gives recommendations for the normal vacuum, normal pressure and emergency venting of fixed roof tanks with or without internal floating roofs constructed to comply with this British Standard.

Provision is made to enable evaluation of venting requirements arising from the following sources.

a) Normal vacuum venting requirements resulting from the maximum rate of export of product from the tank.

b) Normal vacuum venting requirements resulting from the maximum anticipated decrease in tank surface temperature.

c) Normal pressure venting requirements resulting from the maximum anticipated rate of import of product to the tank.

d) Normal pressure venting requirements resulting from the maximum anticipated increase in tank surface temperature.

e) Emergency pressure venting requirements resulting from the exposure of the tank to an external fire.

Any additional causes of normal venting arising from process considerations should be quantified and added to the venting requirements listed in a) to e).

F.2 Normal venting

F.2.1 ***General***

The total normal venting has to cater for at least the sum of product movement and thermal effects.

F.2.2 ***Normal vacuum venting***

F.2.2.1 The normal vacuum venting requirement associated with the maximum rate of product export should be 1.0 m^3 of free air per hour for each 1.0 m^3/h of product export rate for products of any flash point.

F.2.2.2 The normal vacuum venting requirement associated with the maximum anticipated rate of tank surface temperature decrease should be:

a) $\leq$ 4 000 m^3 capacity: 0.18 m^3 of free air per hour for each 1 m^3 of capacity;

b) > 4 000 m^3 capacity: 0.61 m^3 of free air per hour for each 1 m^2 of shell and roof area.

F.2.3 ***Normal pressure venting***

F.2.3.1 For products with a flash point of 38 °C or above, the normal pressure venting requirements associated with the maximum rate of product import should be 1.07 m^3 of free air per hour for each 1.0 m^3/h of product import rate.

F.2.3.2 For products with a flash point below 38 °C, the normal pressure venting requirements associated with the maximum rate of product import should be 2.14 m^3 of free air per hour for each 1.0 m^3/h of product import rate.

F.2.3.3 For products with a flash point of 38 °C or above, the normal pressure venting requirements associated with the anticipated rate of tank surface temperature increase should be 60 % of the values specified in **F.2.2.2**.

F.2.3.4 For products with a flash point below 38 °C, the normal pressure venting requirements associated with the anticipated maximum rate of tank surface temperature increase should be as recommended in **F.2.2.2**.

F.3 Emergency venting

F.3.1 ***Tanks with a frangible roof joint***

No provision need be made for emergency venting for fixed-roof tanks which have a shell to roof joint which is considered frangible according to the provisions of **F.4**.

F.3.2 ***Tanks without a frangible roof joint***

F.3.2.1 *Without additional protection.* For tanks not provided with additional protection as indicated in **F.3.2.2**, the total rate of emergency venting should be as given in Table 10. Full credit should be taken for the venting capacity provided for normal venting since thermal effects can be disregarded during a fire as it can be assumed that no product movement will take place at that time.

F.3.2.2 *Tanks with additional protection.* The total rate of emergency venting should be multiplied by the appropriate factor when the following forms of protection are provided.

a) A factor of 0.5 when drainage away from the tank is provided.

b) A factor of $7.5/t_1$, but limited to a maximum value of 0.075 [where t_1 is the thickness of the insulation (in mm)] when external shell insulation is provided that is considered non-combustible, does not decompose at temperatures below 500 °C and is resistant to damage from fire water impingement.

The provision of any water cooling system will not result in a reduction in the venting requirements.

F.4 Frangible roof-to-shell joint

F.4.1 ***Tanks without anchorages***

For the roof-to-shell joint of tanks without anchorages to be considered frangible (see **F.3.1**) the following should apply.

a) The continuous fillet weld between the roof plates and the top curb angle should not exceed 5.0 mm.

b) The slope of the roof sheeting adjacent to the top curb should not exceed 1 in 5.

c) The effective cross-sectional area of the curb A (in mm^2) as shown in Figure 7 should not exceed:

$$A = \frac{7.07 \times 10^{-3} T}{\tan\theta}$$

where

T is the total weight of shell, stiffening and roof framework supported by the shell but excluding the roof sheeting (in kg);

θ is the slope of roof meridian at roof-to-shell connection (in degrees).

This may result in a curb area less than that required by **8.5.6**.

F.4.2 ***Tanks with anchorage***

In addition to the recommendations of **F.4.1** a) and b), the curb area provided should be checked to ensure failure at a pressure which will not exceed the permitted design stresses in the holding down anchors, tank shell and the roof plating. Curb failure is assumed to occur at a compressive stress of 220 N/mm^2 (i.e. use S_c = 220 N/mm^2 in curb area equation in **8.5.2** to calculate failure pressure).

F.5 Means of venting

F.5.1 ***Normal venting***

F.5.1.1 Normal venting should be accomplished by a pressure relief valve, a vacuum relief valve, a pressure vacuum (PV) valve or an open vent with or without a flame-arresting device complying with **F.5.1.2** to **F.5.1.7**.

F.5.1.2 Relief valves equipped with a weight and lever are not recommended.

F.5.1.3 PV valves are recommended for use on atmospheric storage tanks in which a product with a flash point below 38 °C is stored and for use on tanks containing a product that is heated above its flash point. A flame arrester is not generally considered necessary for use in conjunction with a PV valve because, even at low settings, the gas efflux velocity exceeds the flame speeds of most hydrocarbon gases.

F.5.1.4 Open vents with a flame-arresting device may be used in place of PV valves on tanks in which a product with a flash point below 38 °C is stored and on tanks containing a product that is heated above its flash point.

F.5.1.5 Open vents may be used to provide venting capacity for tanks in which the product with a flash point of 38 °C or above is stored, for heated tanks in which the product's storage temperature is below the product's flash point, for tanks with a capacity of less than 10 m^3 used for storing any product, and for tanks with a capacity of less than 500 m^3 used for storing crude oil.

F.5.1.6 In the case of viscous products, such as cutback and penetration grade asphalts, where the danger of tank collapse resulting from sticking pallets and flame arrester elements is greater than the possibility of flame transmission into the tank, open vents may be used as an exception to the recommendations of **F.5.1.2** to **F.5.1.4**.

Where flame arresters are used, it is good practice to stock spare element assemblies so that they can be removed and replaced on a regular basis depending on local conditions and in this way clean elements would always be available and maintenance time on the tank roof kept to a minimum. Where regular maintenance cannot be guaranteed, the use of flame arresters should be avoided.

F.5.2 ***Emergency venting***

Emergency venting may be accomplished by the use of the following.

a) Larger or additional valves or open vents as limited by **F.5.1.4** and **F.5.1.5**.

b) A gauge hatch that permits the cover to lift under abnormal internal pressure.

c) A manhole cover that lifts when exposed to abnormal internal pressure.

d) A connection between the roof and the shell that is considered frangible in accordance with **F.4**.

e) Other forms of construction demonstrably comparable for the purpose of pressure relief.

F.5.3 ***Vent discharge***

For tanks located inside a building, a discharge from the vents should be to the outside of the building. A weak roof-to-shell connection should not be used as a means of emergency venting tanks inside a building.

For valves with connected pipework on the inlet or discharge side, suitable allowance should be made in the vent sizing for pressure drops occurring in this pipework. Flame arresters will similarly reduce the capacity of the valves or openings.

Table 10 — Requirements for emergency venting

Wetted area	Venting requirements (standard m^3 of free air per hour)
m^2	m^3/h
15	4 800
20	6 200
30	7 800
40	9 200
50	10 400
60	11 500
80	13 500
100	15 200
150	17 300
200	19 000
250	20 400
300	21 600

NOTE 1 No increase in venting requirement is required for tank with wetted area > 300 m^2.

NOTE 2 The wetted area is the total surface area of the shell within 9 m above local grade level.

Appendix G Seismic provisions for storage tanks

NOTE This appendix gives recommendations for the seismic design of storage tanks and is based on the requirements of appendix E of API 650. The zone coefficients used in API 650 have been modified to lateral force coefficients expressed as a ratio of the acceleration due to gravity. This allows application of these calculations to geographical locations outside the USA.

It is recognized that other procedures or additional requirements may be called for by the purchaser or the local authorities in highly active Seismic areas. In this case, specialized local knowledge should be used in agreement between the purchaser, the local authority and the manufacturer which takes into account local requirements, the necessary integrity, soil conditions, etc.

Consideration should be given to design for an operating basis earthquake (OBE) condition and a safe shutdown earthquake (SSE) condition, when establishing site safety requirements.

The following definitions apply.

Operating Basis Earthquake (OBE). The structure should resist this earthquake without any damage. It is suggested to consider the seismic loads with a 10 % probability of being exceeded during the structure's lifetime. Allowable stresses should not be exceeded.

Safe Shutdown Earthquake (SSE). The structure may be damaged by this earthquake, but it should not collapse nor should it impose serious consequential hazards. It is suggested to use the seismic loads with a 1 % probability of being exceeded during the lifetime of the structures. Under this load the ultimate strength should not be exceeded.

G.1 Design loading

G.1.1 *Overturning moment*

The overturning moment due to seismic forces applied to the bottom of the tank shell should be calculated as follows:

$$M = \frac{G_1(T_t X_s + T_r H_L + T_1 X_1) + G_2 T_2 X_2}{102}$$

where

G_1 is the lateral force coefficient given as a ratio of the acceleration due to gravity (see **G.1.3.1**);

NOTE 2 The wetted area is the total surface area of the shell within 9 m above local grade level.

G_2 is the lateral force coefficient given as a ratio of the acceleration due to gravity and determined in accordance with **G.1.3.2**;

H_L is the total height of tank shell (in m);

M is the overturning moment applied to bottom of tank shell (in kN·m);

T_1 is the weight of effective mass of tank contents which moves in unison with tank shell and which is determined in accordance with **G.1.2.1** (in kg);

T_2 is the weight of effective mass of the tank contents which move in the first sloshing mode and which is determined in accordance with **G.1.2.1** (in kg);

T_r is the total weight of tank roof (fixed or floating) plus portion of snow load, if any, as specified by the purchaser (in kg);

T_t is the total weight of tank shell (in kg);

X_1 is the height from bottom of tank shell to centroid of lateral seismic force applied to T_1 and which is determined in accordance with **G.1.2.2** (in m);

X_2 is the height from bottom of tank shell to centroid of lateral seismic force, applied to T_2 and which is determined in accordance with **G.1.2.2** (in m);

X_s is the height from bottom of tank shell to centre of gravity of shell (in m).

G.1.2 *Effective mass of tank contents*

G.1.2.1 The effective mass T_1 and the effective mass T_2 (as defined in **G.1.1**), may be determined by multiplying T_T by the ratios T_1/T_T and T_2/T_T respectively, obtained from Figure 43 for the ratio D/H_T, where:

T_T is the total weight of tank contents (based on a specific gravity not less than 1.0) (in kg);

D is the diameter of tank (in m);

H_T is the maximum filling height of tank from bottom of shell to top of curb angle or overflow which limits filling height (in m).

G.1.2.2 The heights from the bottom of the tank shell to the centroids of the lateral seismic forces applied to T_1, T_2, X_1 and X_2 may be determined by multiplying H_T by the ratios X_1/H_T and X_2/H_T, respectively, obtained from Figure 44 for the ratio of D/H_T.

G.1.2.3 The curves in Figure 43 and Figure 44 are based on a modification of the equations presented in ERDA Technical Information Document 7024.

G.1.3 *Lateral force coefficients*

G.1.3.1 The lateral force coefficient G_1 is to be specified by the purchaser on the basis of seismology records available for the proposed tank site and should be given as a ratio of the acceleration due to gravity.

For a storage tank constructed for service in the UK it is recommended that the lateral force coefficient G_1 be taken as no greater than 0.045.

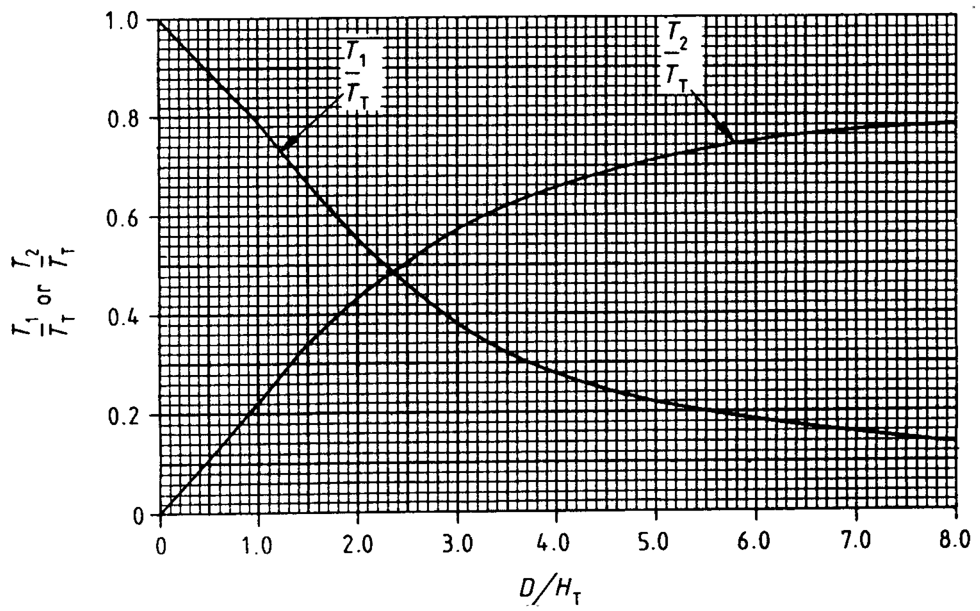


Figure 43 — Effective masses

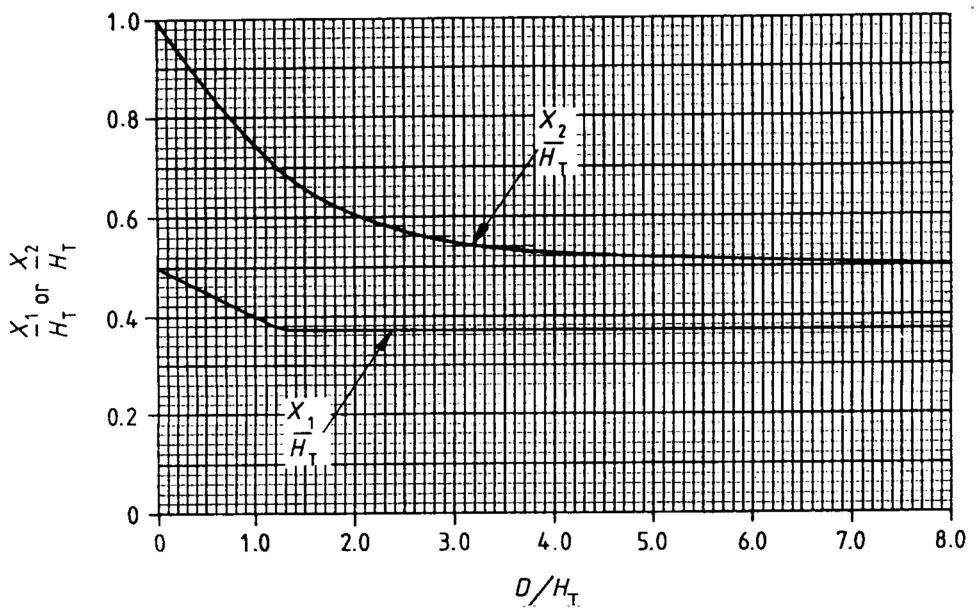


Figure 44 — Centroids of seismic forces

G.1.3.2 The lateral force coefficient G_2 is to be determined as a function of G_1 of the natural period of the first mode sloshing T_s and the soil conditions at the tank site (unless otherwise determined by the method given in **G.1.3.3**) as follows.

a) When T_s is less than 4.5

$$G_2 = \frac{1.25 G_1 J}{T_s}$$

b) When T_s is greater than 4.5

$$G_2 = \frac{5.625 G_1 J}{T_s^{\ 2}}$$

where

J is the site amplification factor from Table 11;

T_s is the natural period in seconds of first mode sloshing.

T_s may be determined from the following expression:

$T_s = 1.8\, K_s D^{½}$

K_s is a factor obtained from Figure 45 for the ratio D/H_T.

G.1.3.3 As an alternative to the method described in **G.1.3.1** and **G.1.3.2** and by agreement between purchaser and manufacturer, G_1 and G_2 may be determined from response spectra established for the specific site of the tank and which may also take into account the dynamic characteristics of the tank. The spectrum for G_1 should be established for a damping coefficient of 2 % of critical. The spectrum for G_2 should correspond to the spectrum for G_1 except modified for a damping coefficient of 0.5 % of critical.

NOTE In no case should the values of G_1 and G_2 be less than those obtained from **G.1.3.1** and **G.1.3.2**.

Table 11 — Soil profile coefficient

Site amplification factor	Soil profile type		
	A[a]	B[b]	C[c]
J	1.0	1.2	1.5

NOTE In locations where the soil profile type is not known in sufficient detail to determine the soil profile type, soil profile C should be assumed.

[a] Soil profile type A is either of two profiles as follows.
a) Rock of any characteristic, either shale-like or crystalline in nature. Such material may be characterized by a shear wave velocity greater than 760 m per second, or
b) Stiff soil conditions where the soil depth is less than 60 m and the soil types overlying rock are stable deposits of sands, gravels, or stiff clays.

[b] Soil profile type B is a profile with deep cohesionless or stiff clay conditions, including sites where the soil depth exceeds 60 m and the soil types overlying rock are stable deposits of sands, gravels, or stiff clays.

[c] Soil profile type C is a profile with soft-to-medium-stiff clays and sands, characterized by 10 m or more of soft-to-medium-stiff clay with or without intervening layers of sand or other cohesionless soils.

G.2 Resistance to overturning

G.2.1 *The tank contents*

Resistance to the overturning moment at the bottom of the shell may be provided by the weight of the tank shell and by the anchorage of the tank shell or, for unanchored tanks, the weight of a portion of the tank contents adjacent to the shell. For unanchored tanks the portion of the contents which may be utilized to resist overturning is dependent on the width of the bottom plate under the shell which lifts off the foundation and may be determined as follows:

$$w_L = 0.1 t_{ba}\sqrt{R_{eb} w_s H_T}$$

except that w_L should not exceed $0.2 w_s H_T D$; and where

w_L is the maximum force of tank contents which may be utilized to resist the shell overturning moment (in kN per metre of shell circumference);

t_{ba} is the thickness of bottom plate under the shell (in mm);

R_{eb} is the minimum specified yield strength of bottom plate under the shell (in N/mm²);

w_s is the maximum density of the contained liquid under storage conditions, to be not less than 1.0 (in g/ml).

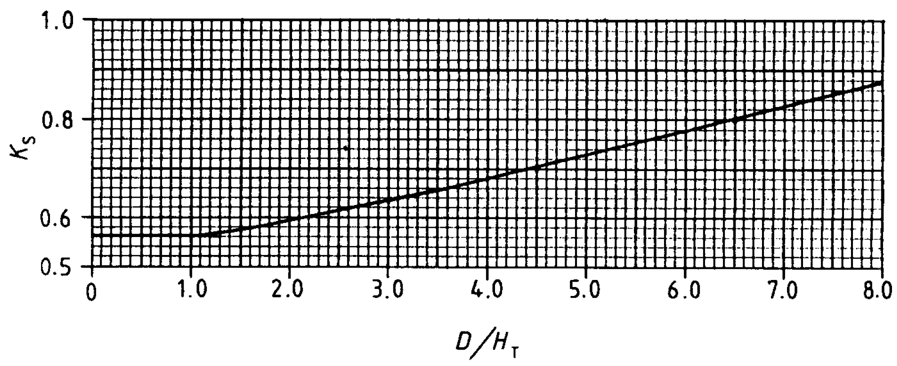


Figure 45 — Factor K_s

G.2.2 ***The thickness of the bottom plate***

The thickness of the bottom plate under the shell, t_{ba}, should not exceed the thickness of the bottom shell course. Where the bottom plate under the shell is thicker than the remainder of the bottom, the width of the thicker plate under the shell in metres, measured radially inward from the shell, should be equal to or greater than:

$$0.1744\frac{w_L}{w_s H_T}$$

NOTE A narrower width of annular plate than that required by the above expression is acceptable provided the resultant reduced w_L resistance loading is adopted in the shell compression computations of **G.3**.

G.3 Shell compression

G.3.1 ***Unanchored tanks***

G.3.1.1 The maximum longitudinal compression force at the bottom of the shell, w_b, may be determined as follows:

a) when $\frac{M}{D^2(w_L + w_t)}$ is equal to or less

than $0.785 w_b = w_t + \frac{1.273M}{D^2}$

b) when $\frac{M}{D^2(w_L + w_t)}$ is greater than 0.785 but

less than or equal to 1.5, w_b may be computed

from the value of the parameter $\frac{w_b + w_L}{w_t + w_L}$ obtained

from Figure 46

where

w_b is the maximum longitudinal shell compression force (in kN per metre of shell circumference);

w_t is the maximum force exerted by tank shell and portion of roof supported by shell (in kN per metre of shell circumference).

G.3.1.2 When $\frac{M}{D^2(w_t + w_L)}$ is greater than 1.5, or

when w_b/t_{bs} exceeds F_a (when calculated using the method described in **G.3.3**), the tank is structurally unstable. In such cases, it is necessary to make the tank stable by one of the following methods:

a) increase the thickness of the bottom plate under the shell, t_{ba} to increase w_L, providing that the limitations of **G.2.1** and **G.2.2** are not exceeded;

b) increase shell thickness, t_{bs};

c) change the proportions of the tank to increase the diameter and reduce the height;

d) anchor the tank in accordance with **G.4**.

G.3.2 ***Anchored tanks***

The maximum longitudinal compression force at the bottom of the shell, w_b (in kN/m), may be determined as follows:

$$w_b = w_t + \frac{1.273M}{D^2}$$

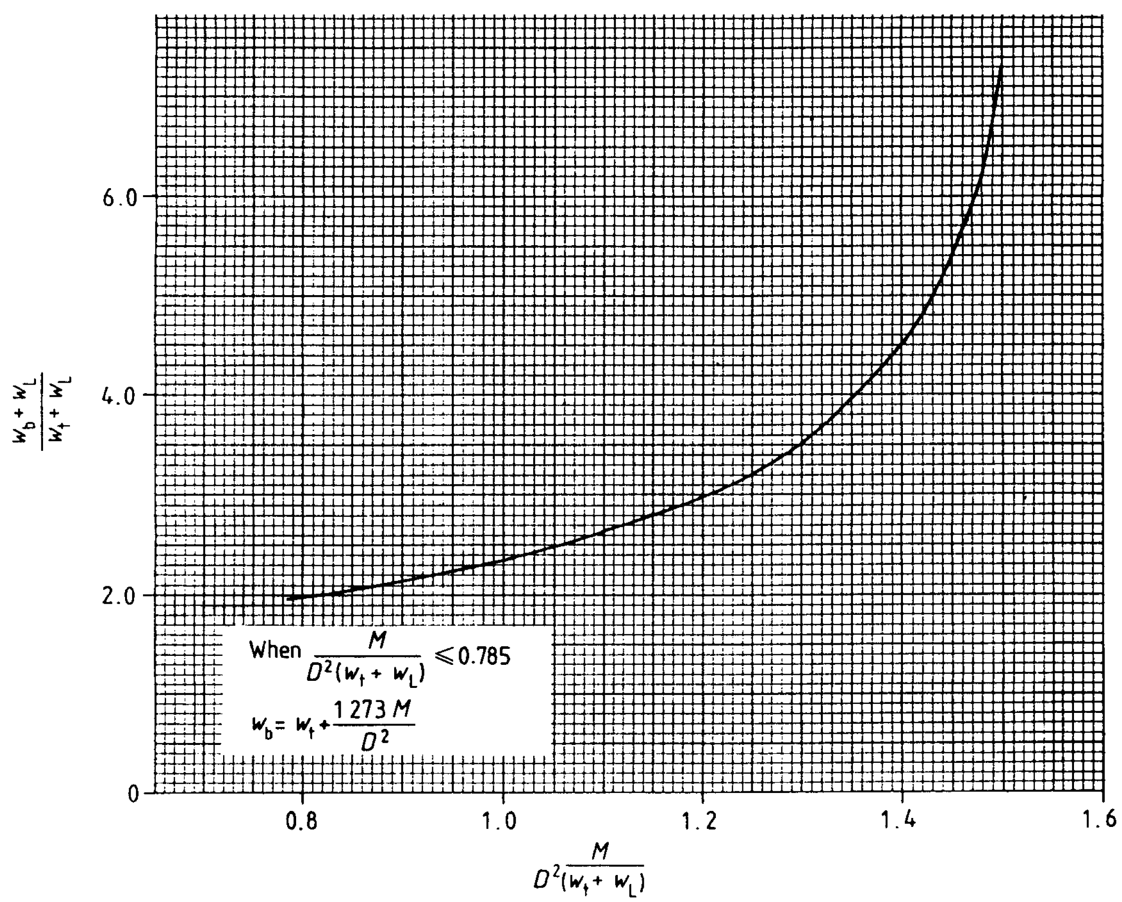


Figure 46 — Compressive force w_b

G.3.3 ***Maximum allowable shell compression***

The maximum longitudinal compressive stress in the shell, w_b/t_{bs} (in N/mm^2), should not exceed the maximum allowable stress, F_a (in N/mm^2), determined as follows:

a) when the value of $\frac{w_s H_T D^2}{t_{bs}^2}$ is greater than 44

$$F_a = 83\frac{t_{bs}}{D}$$

b) when the value $\frac{w_s H_T D^2}{t_{bs}^2}$ of is less than 44

$$F_a = 33\frac{t_{bs}}{D} + 7.5\sqrt{w_s H_T}$$

where

t_{bs} is the thickness, excluding corrosion allowance, of the bottom shell course (in mm);

F_a is the maximum allowable longitudinal compressive stress in the shell (in N/mm^2). The formulae in items a) and b) for F_a take into account the effect of internal pressure due to the liquid contents;

R_{es} is the minimum specified yield strength of the bottom shell course (in N/mm^2).

In no case is the value of F_a to exceed 0.5 R_{es}.

G.3.4 ***Upper shell courses***

If the thickness of the lower shell course calculated to resist the seismic overturning moment is greater than the thickness required for hydrostatic pressure, both excluding corrosion allowance, then unless a special analysis is made to determine the seismic overturning moment and corresponding stresses at the bottom of each upper shell course, the calculated thickness of each upper shell course for hydrostatic pressure should be increased in the same proportion.

G.4 Anchorage of tanks

G.4.1 ***Minimum anchorage required***

When anchorage is considered necessary, it is to be designed to provide a minimum anchorage resistance (in kN per metre of shell circumference) of:

$$\frac{1.273M}{D^2} - w_t$$

The above anchorage resistance is in addition to that required to resist any internal design pressure on low and high pressure tanks.

NOTE Earthquake and wind loading should not be considered as acting concurrently.

G.4.2 ***Design of anchorage***

G.4.2.1 If an anchored tank is not properly designed its shell can be susceptible to tearing. Care should be taken to ensure that the strength of anchorage attachments to the tank shell is greater than the specified minimum yield strength of the anchors so that the anchors yield before the attachments fail. Experience has shown that properly designed anchored tanks retain greater reserves of strength with respect to seismic overload than do unanchored tanks.

In addition to the requirements of **10.1** to **10.5**, the recommendations given in **G.4.2.2** to **G.4.2.4** should be followed.

G.4.2.2 On tanks less than 15 m in diameter, the maximum spacing of the anchors should not exceed 2 m.

G.4.2.3 The allowable tensile stress in the anchorage due to the loadings given in item a) of **10.1** together with the seismic loadings from **G.4.1** should not exceed 1.33 times the stresses given in **10.3**.

G.4.2.4 The attachment of the anchorage to the tank shell and the embedment of the anchor into the foundation should be designed for a load equal to the minimum specified yield strength of the anchorage material multiplied by the as-built minimum cross-sectional area of the anchor. For the attachment of the anchorage to the tank shell and the embedment of the anchor into the foundation the design stress should not exceed 1.33 times that given in **7.1.1**.

G.5 Piping

Suitable flexibility should be provided in the vertical direction for all piping attached to the shell or bottom of the tank. On unanchored tanks subject to bottom uplift, piping connected to the bottom should be free to lift with the bottom or be located so that the distance measured from the shell to the edge of the connecting reinforcement is the width of the bottom plate (as calculated by G.2.2) plus 0.3 m.

Publications referred to

BS 131, *Methods for notched bar tests.*
BS 131-2, *The Charpy V-notch impact test.*
BS 410, *Specification for test sieves.*
BS 449, *The use of structural steel in building.*
BS 476, *Fire tests on building materials and structures.*
BS 476-7, *Surface spread of flame tests for materials.*
BS 882, *Aggregates for natural sources for concrete (including granolithic).*
BS 882-2, *Metric units.*
BS 1201, *Aggregates for natural sources for concrete (including granolithic).*
BS 1201-2, *Metric units.*
BS 1470, *Wrought aluminium and aluminium alloys for general engineering purposes — plate, sheet and strip.*
BS 1503, *Specification for steel forgings (including semi-finished forged products) for pressure purposes.*
BS 1506, *Carbon and alloy steel bars for bolting material.*
BS 1560, *Steel pipe flanges and flanged fittings (normal sizes ½ in to 24 in).*
BS 1560-2, *Metric dimensions.*
BS 2600, *Radiographic examination of fusion welded butt joints in steel.*
BS 2600-1, *Methods for steel 2 mm up to and including 50 mm thick.*
BS 2989, *Specification for continuously hot-dip zinc coated and iron-zinc alloy coated steel: wide strip, sheet/plate and slit wide strip.*
BS 3602, *Specification for steel pipes and tubes for pressure purposes: carbon and carbon manganese steel with specified elevated temperature properties.*
BS 3603, *Specification for steel pipes and tubes for pressure purposes: carbon and carbon alloy steel with specified low temperature properties.*
BS 3792, *Recommendations for the installation of automatic liquid level and temperature measuring instruments on storage tanks.*
BS 3958, *Thermal insulating materials.*
BS 3958-5, *Bonded mineral wool slabs (for use at temperatures above 50 °C).*
BS 3971, *Specification for image quality indicators for industrial radiography (including guidance on their use).*
BS 4211, *Steel ladders for permanent access.*
BS 4300/6, *3105 Sheet and strip.*

BS 4741, *Vertical cylindrical welded steel storage tanks for low-temperature service. Single-wall tanks for temperatures down to – 50 °C.*
BS 4868, *Profiled aluminium sheet for building.*

BS 4987, *Coated macadum for roads and other paved areas.*
BS 5135, *Specification for arc welding of carbon manganese steels.*
BS 5387, *Specification for vertical cylindrical welded storage tanks for low-temperatures down to – 196 °C.*
BS 5930, *Code of practice for site investigations.*
BS 5970, *Code of practice for thermal insulation of pipework and equipment (in the temperature range – 100 °C to + 87 °C).*

BS 6399, *Loading for buildings.*
BS 6399-2, *Code of practice for wind loads.*
BS EN 287, *Approval testing of welders for fusion welding.*

BS EN 287-1, *Steels.*
BS EN 288, *Specification and approval of welding procedures for metallic materials.*
BS EN 288-2, *welding procedures specification for arc welding.*
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