



Flat-bottomed, vertical, cylindrical storage tanks for low temperature service —

Part 2: Specification for the design and construction of single, double and full containment metal tanks for the storage of liquefied gas at temperatures down to – 165 °C

Committees responsible for this British Standard

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British Chemical Engineering Contractors' Association
 British Compressed Gases Association
 British Gas plc
 Concrete Society
 Energy Industries Council
 Engineering Equipment and Materials Users' Association
 Institution of Gas Engineers
 Institution of Mechanical Engineers
 Process Plant Association
 Thermal Insulation Contractors' Association
 Welding Institute

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Foreword

This Part of BS 7777 has been prepared under the direction of the Pressure Vessels Standards Policy Committee.

Flat-bottomed, vertical, cylindrical, storage tanks for refrigerated liquefied gases have traditionally been of the single containment design where the liquid is contained in a single shell surrounded by a conventional low bund wall at a considerable distance. Where a double shell construction was used, the outer shell was mainly there to contain the insulation.

These tanks were built according to two British Standards:

BS 4741:1971, *Specification for vertical cylindrical welded steel storage tanks for low temperature service: single wall tanks for temperatures down to – 50 °C.*

BS 5387:1976, *Specification for vertical cylindrical welded storage tanks for low-temperature service: double-wall tanks for temperatures down to – 196 °C.*

Until the 1970s it was normal practice to store all refrigerated products in single containment tanks. Since that time it has increasingly become the practice for the inner tank for hydrocarbons or ammonia to be surrounded by an outer tank or wall. It is still the practice to store liquid oxygen, liquid nitrogen or liquid argon in single containment tanks. This outer tank or wall is intended to prevent the release of the liquefied products into the surrounding area in case of leakage from or damage to the inner tank. This philosophy results in increased safety for the surrounding area. Such constructions are known as double containment tanks and full containment tanks.

Depending on the lowest service temperature, the inner tank may be made from carbon-manganese steel, low nickel steel, 9 % nickel steel, aluminium or stainless steel. The double containment tanks and full containment tanks generally have outer tanks or walls made from prestressed concrete, reinforced concrete with an earth embankment or one of the metals specified for the inner tank. BS 4741 and BS 5387 specified the requirements for single containment tanks only and consequently did not include the requirements for material selection, design, construction, loading cases, etc. that are necessary for double containment tanks and full containment tanks.

To redress this situation, the Storage Tank Committee of The Engineering Equipment and Materials Users' Association (EEMUA) published in 1986 *Recommendations for the design and construction of refrigerated liquefied gas storage tanks*, Publication No. 147[1]. The intention of EEMUA was that this document would form the basis of a British Standard to be published a few years later. Together, BS 7777-1 to BS 7777-4 supersede BS 4741:1971 and BS 5387:1976, which are withdrawn.

Although experience has demonstrated that the risk of failure of a single containment tank designed and fabricated in accordance with British Standards is very low, this can be further reduced by more stringent requirements for material selection, design, construction, inspection and testing. For certain stored products, however, the consequences of failure may be considered so great that an outer tank or wall is deemed necessary. Thus a further reduction of risk of failure can be achieved through the use of a double or full containment storage concept. The definitions of single, double and full containment tanks are given in **3.1** of BS 7777-1:1993.

The selection of the storage concept should take into account the location, the operational conditions and the environmental conditions. This standard covers only flat-bottomed, cylindrical, stand-alone, storage tanks. However, it is not intended to exclude the use of other concepts and designs which have been proven in service.

This British Standard comprises four Parts:

— *Part 1: Guide to the general provisions applying for design, construction, installation and operation;*

— *Part 2: Specification for the design and construction of single, double and full containment metal tanks for the storage of liquefied gas at temperatures down to $-165\text{ }^{\circ}\text{C}$;*

— *Part 3: Recommendations for the design and construction of prestressed and reinforced concrete tanks and tank foundations, and for the design and installation of tank insulation, tank liners and tank coatings;*

— *Part 4: Specification for the design and construction of single containment tanks for the storage of liquid oxygen, liquid nitrogen or liquid argon.*

NOTE This standard has been written in the form of a practice specification (see clause 6 of PD 6501-1:1982).

To comply with this specification, the user has to comply with all its requirements. The user may responsibly depart from the recommendations, but would be expected to have good reasons for doing so.

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

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

Summary of pages

This document comprises a front cover, an inside front cover, pages i to vi, pages 1 to 58, 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.

1 Scope

This Part of BS 7777 specifies requirements, based on the loading cases given in Table 1 of BS 7777-1:1993, for the materials, design, fabrication, inspection and testing of metal components of single, double and full containment storage tanks.

NOTE 1 A reference list of metal components is given in Table 1.

NOTE 2 Where it is not possible to specify requirements which can be verified, but it is considered that the information available demands consideration, commentary and recommendations are added to the text.

2 References

2.1 Normative references

This Part of BS 7777 incorporates, by reference, provisions from specific editions of other publications. These normative references are cited at the appropriate points in the text and the publications are listed on page 59. Subsequent amendments to, or revisions of, any of these publications apply to this Part of BS 7777 only when incorporated in it by updating or revision.

2.2 Informative references

This Part of BS 7777 refers to other publications that provide information or guidance. Editions of these publications current at the time of issue of this standard are listed on page Inside back cover, but reference should be made to the latest editions.

Table 1 — Reference list of metal components for single, double and full containment tanks

Subclause reference ^a	Description of tank component	Typical stored products
7.1	Single containment: steel outer container	Ethane, ethylene, liquid natural gas (LNG)
7.2	Single containment: inner tank	
7.3	Single containment: steel tank	Butane, ammonia, propane, propylene
8.1	Double containment: inner tank	Butane, ammonia, propane, propylene, ethane, ethylene, LNG
8.2	Double containment: steel outer tank	
9.1	Full containment: inner tank	
9.2	Full containment: steel outer tank	

^a More detail is given at respective clause references for particular tank types.

3 Definitions

For the purposes of this Part of BS 7777, the definitions given in clause 3 of BS 7777-1:1993 apply, together with the following.

3.1

manufacturer

the organization carrying out the shop fabrication

3.2

erector

the organization carrying out the construction on site

3.3

electrode manufacturer

a specific manufacturer of electrodes

3.4

designer

the organization carrying out the engineering design of the tank

4 Design conditions

The design conditions referred to in this Part of BS 7777 shall be those given in clause 4 of BS 7777-1:1993.

5 Information to be exchanged between the purchaser and the contractor

5.1 Information to be supplied by the purchaser

The information to be supplied by the purchaser shall be as given in 5.1 of BS 7777-1:1993.

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

The optional and/or alternative information to be supplied by the purchaser shall be as given in 5.2 of BS 7777-1:1993.

5.3 Information to be agreed between the purchaser and the contractor

The information to be agreed between the purchaser and the contractor shall be as given in 5.3 of BS 7777-1:1993.

In addition, the purchaser and manufacturer shall agree on the areas of the tank whose material is to be impact tested (see 6.2.2).

6 Materials

6.1 Materials for inner or outer tank designed to contain refrigerated liquid

COMMENTARY AND RECOMMENDATIONS ON 6.1. *The material selection given in this clause does not constitute a new interpretation of low temperature toughness capabilities of carbon-manganese and low nickel steels already in use for equipment applications at design temperatures less than 0 °C. It differs from these by the incorporation of some of the environmental safety considerations associated with large low temperature and cryogenic temperature storage installations.*

The degradation effect of welding has been considered in material selection. There is the intent to specify stringent quality control Charpy V-notch impact test requirements for base material subject to welding (see Annex A), which, in conjunction with the design, inspection and testing requirements in this Part, should satisfy the provisions set out in BS 7777-1. The tensile testing of 9 % nickel steel weld metal using strain gauge testing specimens should be in accordance with Annex B.

The use of aluminium for the inner tank is by agreement between the purchaser and manufacturer (see Annex C).

6.1.1 Plate and fitting materials

Plate materials used for the manufacture of tanks shall be as follows.

- a) Type I steel: normalized carbon-manganese steel conforming to grade P275 NL1 or NL2 or grade P355 NL1 or NL2 of BS EN 10028-3:1993.

NOTE BS 1501-1 was superseded by BS EN 10028 and has been withdrawn. Existing steels 224 grade 430 and 510 grade LT 50 conforming to BS 1501-1 should be treated as type I steel.

- b) Type II steel: improved toughness carbon-manganese steel.

- c) Type III steel: low nickel steel.

- d) Type IV steel: 9 % nickel steel conforming to type 510 of BS 1501-2:1988.

- e) Type V steel: improved 9 % nickel steel conforming to type 510 improved of BS 1501-2:1988.

- f) Type VI steel: austenitic stainless steel conforming to BS 1501-3:1990.

The steel types for the various products shall be as given in Table 2.

Longitudinal Charpy V-notch impact test requirements shall be as specified in Table 3. In addition, the general and testing requirements of BS 1501-2:1988, BS 1501-3:1990 and BS EN 10028-3:1993 shall be satisfied. Other product forms shall conform to this Part of BS 7777, and to the general and testing requirements of the following standards:

- a) for forgings, BS 1503:1989;
b) for piping, BS 3603:1991 and BS 3605-1:1991.

Table 2 — Material types for tank shell and bottom

Product	Single containment	Double or full containment	Typical product storage temperature
Butane	Type II	Type I	– 10 °C
Ammonia	Type II	Type I	– 35 °C
Propane/ propylene	Type III	Type II	– 50 °C
Ethane/ ethylene	Type IV	Type IV	– 105 °C
LNG	Type V or VI	Type IV ^a	– 165 °C

^a For thicknesses greater than 30 mm and less than or equal to 40 mm, Type V or VI is necessary.

6.1.2 Maximum shell plate thickness

The maximum shell plate thicknesses with regard to material type shall be in accordance with Table 4. The measured thickness at any point:

- a) more than 15 mm from the edge of any steel shell plate, where the thickness is to conform to 7.1.4.2, or
b) more than 15 mm from the edge of any roof plate, where the thickness is to conform to 7.1.5.3, or
c) on the bottom or annular plate,

shall be not less than the specified thickness less half of the total thickness tolerance specified in BS EN 10025:1990.

The measured thickness at any point:

- 1) more than 15 mm from the edge of any steel shell plate, where the thickness is to conform either to 7.1.4.2 or 7.2.4.3, or
2) more than 15 mm from the edge of any roof plate, where the thickness is to conform to 7.1.5.4, shall be not less than the calculated minimum thickness.

Table 3 — Longitudinal Charpy V-notch impact testing

Classification	Steel type	Tested per plate ^{ab}	120 J tested per 40 t batch ^c
Type I	Normalized carbon-manganese	27 J at – 50 °C	Not required
Type II	Improved toughness carbon-manganese	27 J at – 50 °C – ΔT^d	– 20 °C
Type III	Low nickel steel	27 J at – 80 °C – ΔT^d	– 50 °C
Type IV	9 % nickel steel	35 J at – 196 °C	Not required
Type V	Improved 9 % nickel	100 J at – 196 °C	Not required
Type VI	Austenitic stainless steel	No impact testing required	

^a Energy value is the minimum average of three specimens, with only one single value less than the value specified and with no single value less than 75 % of the value specified.

^b For material thickness less than 11 mm, 10 mm × 5 mm sub-size specimens are to be used, and demonstrate 70 % of the values specified in this table. For Type V steel, the value is to be 50 % of the value specified in this table.

^c Impact testing is carried out on each plate to demonstrate the required impact value. In addition, testing at a frequency of one test per 40 t batch is to be carried out to demonstrate the 120 J requirement (see Annex A). The definitions of plate and batch are given in BS EN 10025.

^d Reference should be made to Annex A.

COMMENTARY AND RECOMMENDATIONS ON 6.1.2.

Local thinning remote from the plate edge, due to rolled-in scattered scale on the surface of 9 % nickel steel, is acceptable provided that the measured thickness is not less than 90 % of the calculated thickness of the plate. This is permissible only when design thickness is based on weld metal strength and not the stronger plate material property value.

Table 4 — Maximum shell plate thickness

Material type	Maximum shell thickness ^a
Type I	30 mm
Types II and III	25 mm
Types IV and V	30 mm ^b
Type VI	25 mm

^a When material thicknesses are required in excess of these values, additional requirements to maintain the same level of safety are to be agreed between purchaser and manufacturer.

^b See footnote to Table 2.

6.1.3 Welding

The welding procedure used for the construction of steel tanks shall be that used in the welding procedure approval tests.

All welding procedures shall be approved in accordance with 11.12.

Weld metal toughness for the shell, bottom annular and roof compression area butt welds, including the connections between bottom annular-to-shell, and shell nozzles, mountings and other permanent attachments, shall be in accordance with Table 5.

6.1.4 Bolting materials

Bolting materials shall be in accordance with BS 1506:1990 and, when non-austenitic steels are used, shall demonstrate a fracture toughness of 27 J at the design temperature.

Table 5 — Weld metal Charpy V-notch impact test energy

Weld metal for designated steel type	Charpy V-notch impact test energy ^a
For materials used at ambient temperatures	27 J at – 10 °C
For Type I steels	50 J at – 30 °C ^b
For Type II steels	50 J at – 50 °C ^b
For Type III steels	50 J at – 80 °C ^b
For Type IV steels	35 J at – 196 °C ^c
For Type V	35 J at – 196 °C ^c
For Type VI	Not required

NOTE Where austenitic weld metal is used for welding Type II or Type III steels, Charpy V-notch impact testing of the weld metal is not required.

^a Energy value is the minimum average of three specimens, with only one single value less than the value specified and with no single value less than 75 % of the value specified.

^b The intent of this specification is to ensure that the production welds in the tank meet the 20 J minimum at the test temperature given above. In order to achieve this, the procedure test of weld metal for Types I, II and III steels is required to demonstrate a higher Charpy V-notch energy value to compensate for the scatter of results inherent in Charpy V testing of weld materials. Employing the foregoing welding procedure, production test plates are normally unnecessary, and are not a feature of this standard. However, if production test plates are called for by the purchaser, minimum average energy values of 27 J for three specimens with no single value less than 20 J are required at the test temperature given.

^c The minimum average impact energy for the weld metal for Types IV and V is based on the high nickel, austenitic weld metal. In the event of weld metal being offered in composition matching that of 9 % nickel plate, additional specialist advice should be obtained.

COMMENTARY AND RECOMMENDATIONS ON 6.1.4.

Where austenitic steel is used, such as grades 304, 321 or 347 of BS 1506, bolts may relax on cooling to subzero temperatures. This is caused by a permanent transformation of the structure from austenite to martensite which results in an increase of length. The extent of transformation increases with the applied stress.

Bolts that cannot be retightened after cooling should be made from steel bar having a stable structure, such as 25 Cr 20 Ni steel in accordance with BS 1501-3 (BS 1501-310S16), or nitrogen bearing austenitic steel in accordance with BS 1501-3 (BS 1501-347S51) or with BS 1501-3 (BS 1501-304S61).

6.1.5 Mountings

Nozzle bodies and insert plates shall be of the same specified nominal strength as the plates to which they are attached.

Permanent attachments, insert plates, nozzle bodies and flanges shall meet the notch ductility requirements of 6.1.1.

COMMENTARY AND RECOMMENDATIONS ON 6.1.5.

For 9 % nickel steel tanks the nozzle body should be made from 9 % nickel steel. Austenitic stainless steel pipe or flange may be welded to the nozzle body provided that the butt weld is located at a distance greater than that calculated from the equation:

$$d = \sqrt{(rt)}$$

where

d is the welding distance for austenitic stainless steel measured from the face of the reinforcement (in mm);

r is the inside radius of the nozzle body (in mm);

t is the thickness (in mm).

6.2 Steel for outer tanks and outer containers**6.2.1 Outer liquid containing tanks, with internal or external insulation, for double containment or full containment**

For outer tank shells, bottoms, reinforcing plates, mountings and permanent attachments, material shall be in accordance with Table 2 for double containment tanks or full containment tanks.

For compression area, roof, roof structure and roof fittings where the minimum design temperature is based on the product temperature, material shall be in accordance with Table 2 for double or full containment tanks.

Where the minimum design temperature is based on the ambient value, steel for outer tank roof plates, roof structure, roof fittings and, where applicable, also for the outer tank compression area, shall be in accordance with Table 6.

COMMENTARY AND RECOMMENDATIONS ON 6.2.1. It is permissible to increase the maximum thickness of the roof compression area to $1.5 \times$ the permitted limits (see 6.1.2), where the minimum design temperature is based on the product temperature, and 1.5×35 mm, where the minimum design temperature is based on ambient temperature.

Table 6 — Steels for outer tank compression area, roof and roof structure where the minimum design temperature is based on ambient temperature

Minimum design metal temperature ^a °C	Thickness mm	Material ^b
$T \geq 0$	$t \leq 15$	BS EN 10025:1990 Fe 430 B or Fe 510 B
	$15 < t \leq 35$	BS EN 10025:1990 Fe 430 C or Fe 510 D1
$T \geq -20$	$t \leq 15$	BS EN 10025:1990 Fe 430 B or Fe 510 C
	$15 < t \leq 35$	BS EN 10025:1990 Fe 430 D1 or Fe 510 DD1

^a See 6.2.2.
^b Other materials may be used provided they are equivalent to those specified, and provided the purchaser and manufacturer agree to such a substitution.

6.2.2 Outer gas containers for single containment tanks

Material selection for an outer gas container shall be based on the minimum design metal temperature of the tank shell, bottom or roof. All material used shall be in accordance with Table 7.

All material, such as forgings or piping, that is to be welded to the outer container shall have a carbon content of less than 0.25 %.

The purchaser and manufacturer shall agree on the areas of the tank whose material shall be impact tested at a temperature determined in accordance with Table 7, the ruling thickness of the part and the minimum design metal temperature (see 5.3).

The notch ductility of a reinforcing plate shall be determined by reference to its maximum thickness and to Table 7. If the plate is more than 35 mm thick, the steel shall be impact tested at $-50\text{ }^{\circ}\text{C}$ and shall have an impact energy value of not less than 27 J.

The reference thickness of a permanent attachment, reinforcing plate, nozzle body or structural item shall be taken as equal to its maximum thickness. A nozzle flange shall have a reference thickness that is either the thickness of the branch to which the flange is attached or 25 % of the flange thickness, whichever is the greater.

Table 7 — Steel for outer containers for single containment tanks

Minimum design metal temperature ^a T °C	Thickness t mm	Material ^b
$T \geq +10$	$t \leq 30$	BS EN 10025:1990 Fe 360 B, Fe 430 B or Fe 510 B
$+10 > T \geq 0$	$t \leq 25$	BS EN 10025:1990 Fe 360 B, Fe 430 B or Fe 510 B
	$25 < t \leq 35$	BS EN 10025:1990 Fe 360 C, Fe 430 C or Fe 510 D1
$0 > T \geq -20$	$t \leq 12.5$	BS EN 10025:1990 Fe 360 B, Fe 430 B or Fe 510 B
	$12.5 < t \leq 20$	BS EN 10025:1990 Fe 360 C, Fe 430 C or Fe 510 C
	$20 < t \leq 35$	BS EN 10025:1990 Fe 360 D1, Fe 430 D1 or Fe 510 DD1
^a See 6.2.2.		
^b Other materials may be used provided they are equivalent to those specified, and provided the purchaser and manufacturer agree to such a substitution.		

The welding consumables used for the welding of the outer container shall be those used for the qualification of the welding procedure. 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 and a thickness greater than 13 mm.

COMMENTARY AND RECOMMENDATIONS ON 6.2.2. *The minimum design metal temperature for the United Kingdom is $-10\text{ }^{\circ}\text{C}$. For areas outside the United Kingdom, the minimum design metal temperature is the lowest daily mean temperature i.e. $0.5 \times (\text{maximum temperature} + \text{minimum temperature})$.*

7 Design of components for single containment tank

7.1 Steel outer container of double shell single containment tank

NOTE An illustration of a steel outer container of a double shell, single containment tank is given in Figures 1c and 1d of BS 7777-1:1993.

7.1.1 Outer container materials

All materials used for the manufacture of outer containers shall be in accordance with clause 6.

7.1.2 Outer container loadings

The outer container loadings shall be in accordance with Table 1 of BS 7777-1:1993.

7.1.3 Design of the outer container bottom

7.1.3.1 General

The container bottom shall be fully supported by the foundation.

The minimum thickness of both sketch or annular plates shall be 6 mm and the minimum length of straight edge of a sketch plate shall be 500 mm.

Containers with a bottom shell course greater than 10 mm thick shall have a ring of butt-welded annular plates with a minimum plate thickness of 8 mm.

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

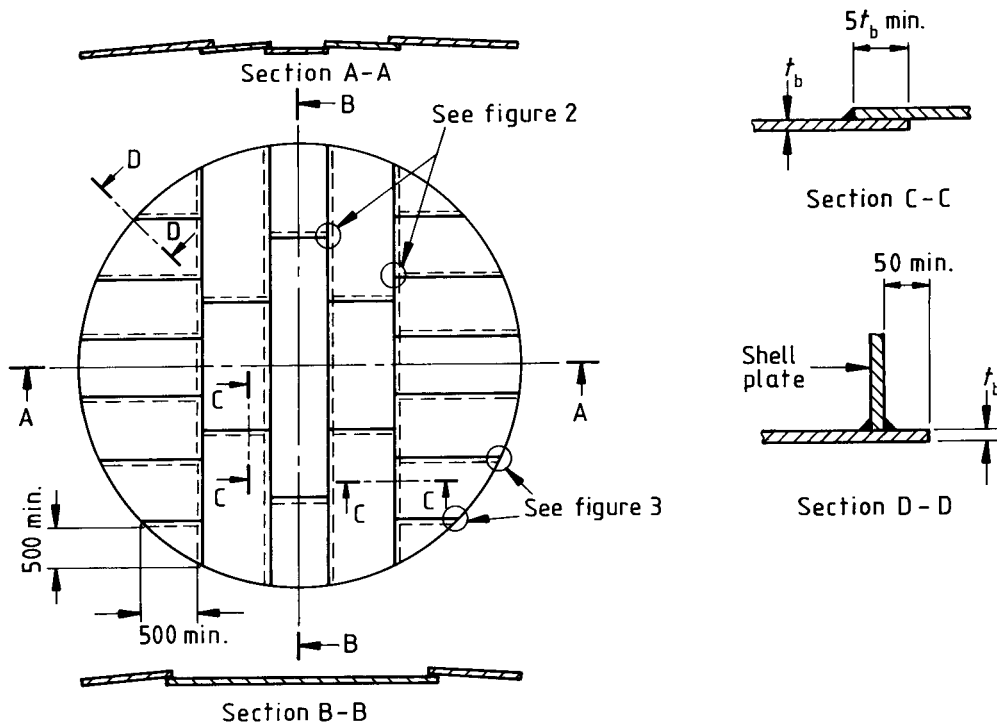
Annular plates shall have a minimum width of 500 mm.

The minimum distance from the outer surface of the bottom shell plate to the outer edge of the bottom plate shall be 50 mm (see section D-D and section E-E of Figure 1).

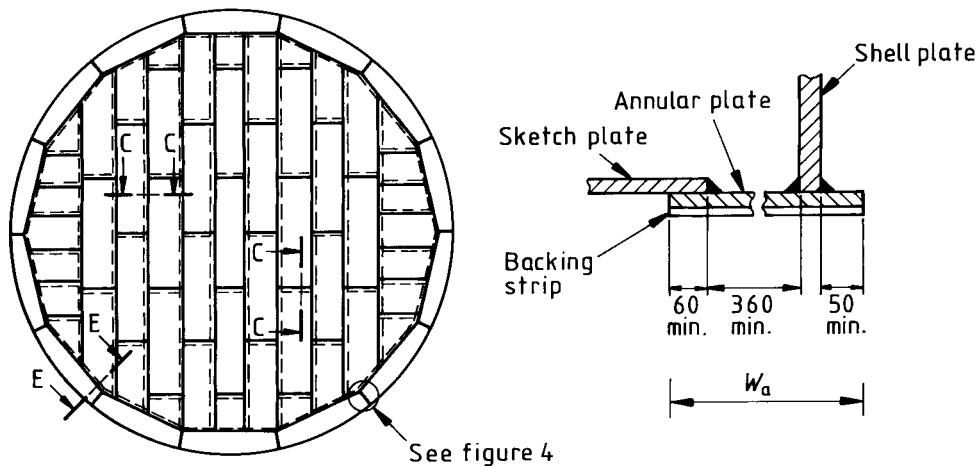
COMMENTARY AND RECOMMENDATIONS ON 7.1.3.1. *Recommendations for the construction of foundations are given in BS 7777-3.*

A container with a bottom shell course not greater than 10 mm thick may have a ring of annular plates, or it may be constructed with sketch plates to the perimeter.

For the minimum distances, reference should be made to section D-D of Figure 1.



a) With sketch plates to perimeter



b) With annular plates at perimeter

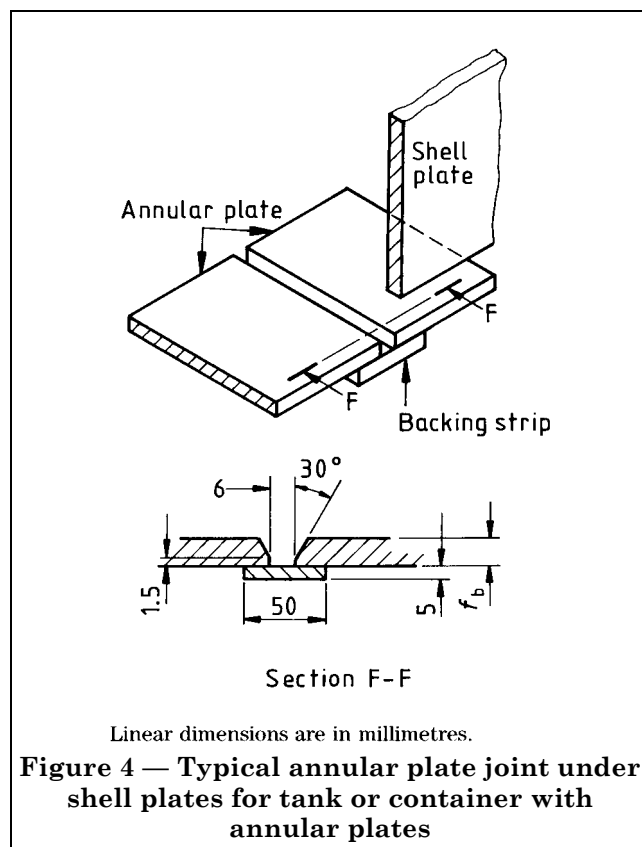
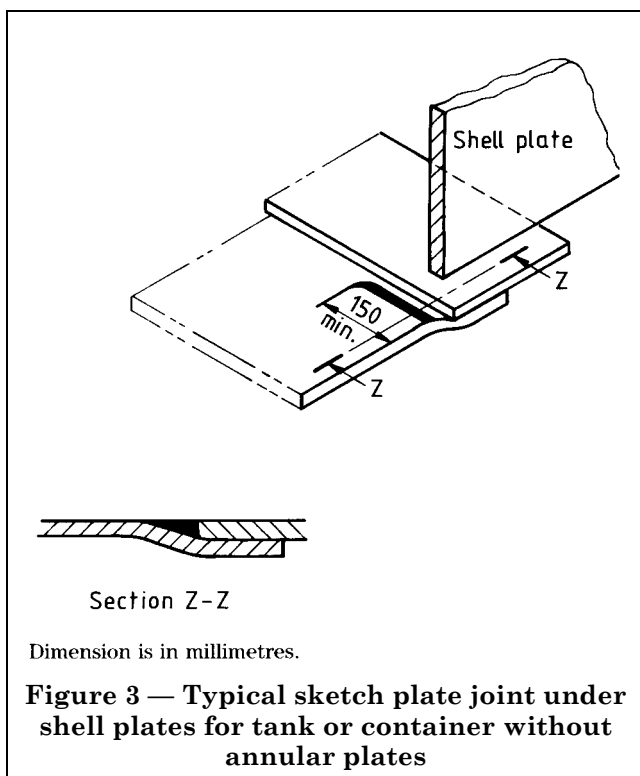
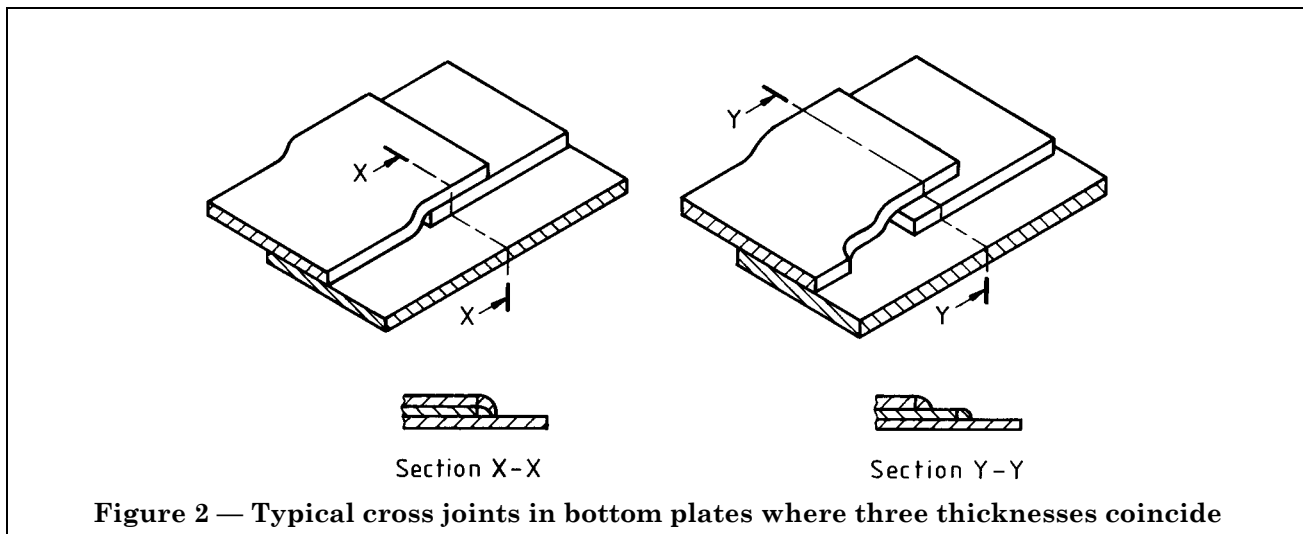
All dimensions are in millimetres.

$W_a = 500$ minimum for outer containers (see 7.1.3.1)

$W_a = 650$ minimum for tanks (see 7.2.3.1)

Section E - E

Figure 1 — Typical bottom layout for tank or container



7.1.3.2 Bottom plating

Layouts and details for tank bottom plating shall be in accordance with Figure 1 to Figure 4.

All joints in rectangular and sketch plates shall be lapped and 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 1).

The rectangular plates and the sketch plates shall be lapped over the annular ring of segmental plates, where used, and welded on the top side only with a full fillet weld, the minimum lap being 60 mm (see section E-E of Figure 1).

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 (see section X-X and section Y-Y of Figure 2).

For tanks where annular plates are not used, the ends of the joints in the sketch plates under the bottom course of shell plates shall be welded for a minimum distance of 150 mm (see Figure 3).

For tanks where annular plates are used, the radial seams connecting the ends of the annular segmental plates shall be butt welded with a backing strip the minimum thickness of which shall be 5 mm (see section F-F of Figure 4).

The attachment between the bottom edge of the lowest course of shell plates and the bottom sketch plate or annular plate shall be fillet welded continuously on both sides of the shell plate. The leg length of both fillet welds shall be equal to the thickness of the shell plate or sketch plate or annular plate whichever is the least (see section D-D and section E-E of Figure 1).

7.1.4 Outer container shell design

7.1.4.1 Shell design stress

The design stress in any plate shall be 260 N/mm^2 or two-thirds of the material minimum yield strength (in N/mm^2) at room temperature, whichever is the lesser. This shall apply to all container courses.

7.1.4.2 Shell thickness

The nominal thickness of shell plates shall be not less than that given in Table 8. The maximum thickness of shell plates shall be 35 mm.

The forces in the outer shell shall be calculated from the most severe combination of loadings determined from Table 1 of BS 7777-1:1993.

The following equation shall be used in calculating the minimum thickness of shell plates for internal pressure:

$$t = \frac{pD}{20S} + c$$

where

- t is the calculated shell plate thickness (in mm);
- p is the internal pressure, as a combination of internal gas pressure and insulation pressure [in mbar (gauge)^a];
- S is the allowable design stress (in N/mm^2);
- D is the container diameter (in m);
- c is the corrosion allowance (in mm).

^a $1 \text{ mbar} = 10^{-3} \text{ bar} = 100 \text{ N/m}^2 = 100 \text{ Pa}$.

Table 8 — Container nominal shell plate thickness

Nominal container diameter D m	Nominal shell thickness ^a mm
$D < 10$	5
$10 \leq D < 30$	6
$30 \leq D < 60$	8
$60 \leq D < 75$	10
$75 \leq D$	12.5

^a The requirement for minimum nominal thickness is needed for construction purposes, and may include any corrosion allowance, provided that the shell is shown by calculation to be safe in the corroded condition and to be in accordance with 7.1.4.2 and 7.1.4.3.

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

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

where

- S_c is the allowable compressive stress (in N/mm^2);
- t is the shell plate thickness at the point under consideration (in mm);
- c is the corrosion allowance, if applicable (in mm);
- R is the radius of the container (in m);
- G is a factor, for different loading combinations, as follows:
 - = 1.00 for deadweight above the point under consideration plus insulation load plus 50 % of pipe load plus superimposed load.

- = 1.25 for deadweight above the point under consideration plus insulation load plus pipe load plus wind load plus 50 % of superimposed load.
- = 1.33 for deadweight above the point under consideration plus insulation load plus pipe load plus seismic load plus 50 % of superimposed load.

COMMENTARY AND RECOMMENDATIONS ON 7.1.4.2. *The maximum allowable compressive stress varies with different loading combinations. The design should take into account the different values of factor G for different loading combinations.*

Since the calculated container thickness is generally significantly less than that for a tank designed to contain a liquid, the design of the shell should be checked. This ensures that it is capable of withstanding the axial compressive load resulting from the roof weight, shell self-weight, snow load, internal negative pressure loading, live load, loads transmitted to the shell from loose-fill insulation, wind and seismic loads.

7.1.4.3 Shell stiffeners for wind loading and internal negative pressure loading

Shell stiffeners shall be fitted where there is a requirement to maintain roundness over the full height of the shell under wind loading and/or internal negative pressure loading.

Shell stiffeners, though not required to carry panel loading, shall be fitted to prevent preferential local buckling of the shell.

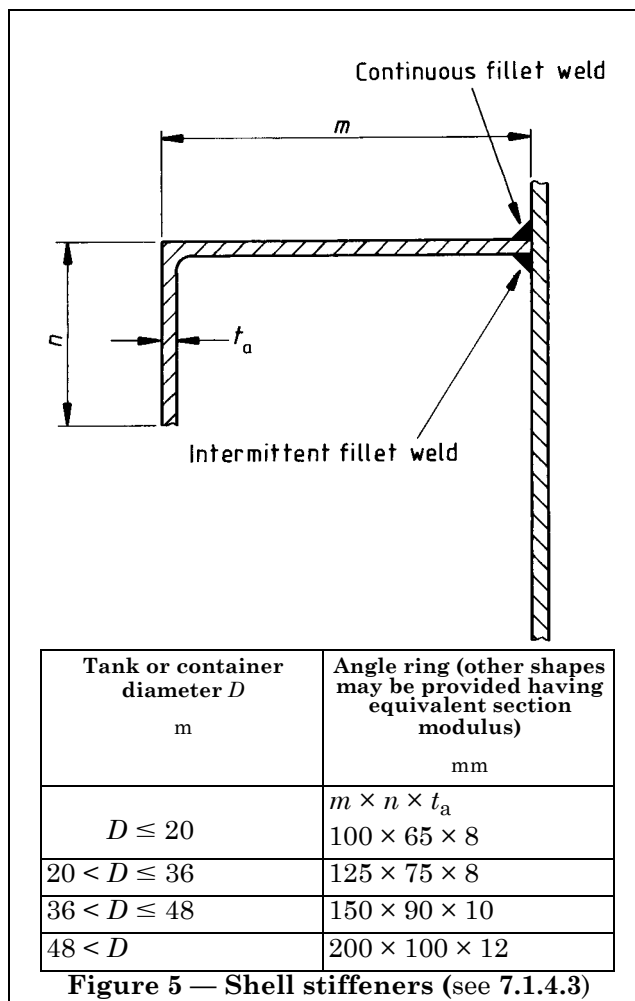
The fixing of shell stiffeners shall be in accordance with Figure 5.

The vertical positioning of shell stiffeners shall be calculated by determining the height of a complete shell of equivalent stability, at the same diameter and of the same thickness as the top course of shell plating.

A stiffener ring shall be located not less than 150 mm from a main horizontal circumferential seam.

The wind speed used in the calculation shall be in accordance with BS 7777-1:1993.

The design internal negative pressure shall be 6 mbar (gauge).



The size and location of shell stiffeners shall be determined from the formulae as follows:

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

$$H_E = \Sigma H_e$$

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

$$H_p = K \left(\frac{t_{\min}}{D^3} \right)^{\frac{5}{2}}$$

where

D	is the tank or container diameter (in m);
t_{\min}	is the thickness of the top course (in mm);
t	is the thickness of each course in turn (in mm);
h	is the height of each course in turn (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 internal negative pressure for design [in mbar (gauge)];
K	is a factor;
H_p	is the maximum permitted spacing of stiffeners on shells of minimum thickness (in m).

COMMENTARY AND RECOMMENDATIONS ON 7.1.4.3. *The size of stiffeners is not related to the design loads but is determined, with respect to tank or container diameter, in accordance with the table of Figure 5.*

An analysis of an equivalent shell, in association with the required wind and internal negative pressure design criteria, determines the number of stiffeners. In many cases these stiffeners are located on the top course, or on a course of similar thickness, but if the location is not on such courses, the actual positioning should be determined by converting the equivalent shell course heights back to their actual values.

Self-supporting fixed-roof tanks, or containers with roof structure, are considered to be adequately stiffened at the top of the shell by the roof structure.

Guidance on shell stiffener design is given in Annex D, with an example of the calculation.

7.1.4.4 Shell plate arrangement

The container shall be designed to have all courses vertical.

The diameter on the centre line of each course shall be equal to the nominal diameter of the container.

COMMENTARY AND RECOMMENDATIONS ON 7.1.4.4. *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 distortion.*

7.1.4.5 Shell joints

Shell seams shall be butt welded.

The procedure used for welding vertical and horizontal butt welds shall be as qualified in the welder approval tests (see 11.12).

COMMENTARY AND RECOMMENDATIONS ON 7.1.4.5. *It is recognized that in practice continuous full penetration welds may not always be achieved. This need not be cause for rejection provided that the lack of full penetration is intermittent and longitudinal. Discretion is recommended in rectifying a lack of penetration since repair welds may not improve the integrity of the tank.*

7.1.5 Outer roof design

7.1.5.1 Roof loads

The roof shall be designed to support the loadings given in Table 1 of BS 7777-1:1993.

7.1.5.2 Type of roof

The roof shall be of the dome or cone type.

For a cone roof, the slope shall be 1 in 5.

For a dome roof, the radius of curvature shall be subject to agreement between the purchaser and the manufacturer, but shall be in the range of 0.8 to 1.5 × the diameter of the shell.

COMMENTARY AND RECOMMENDATIONS ON 7.1.5.2. *Other cone roof slopes should be agreed between the purchaser and manufacturer.*

7.1.5.3 Roof plating with supporting structure

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

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

The roof-supporting structure shall be designed in accordance with BS 449-2:1969 and with BS 5950. The spacing of roof purlins for cone roofs shall be such that the span between them does not exceed 1.70 m. Where one edge of the panel is supported by the top curb of the shell, the maximum span permitted shall be 2.0 m.

Lapped roof plates shall be continuously fillet welded on the outside, with a minimum lap of 25 mm.

Seams in the roof plating, that are included as part of the compression area, shall be butt welded.

The roof plate thickness shall be checked for internal pressure using the equations of 7.1.5.4. The joint efficiency shall be taken as 1.0 for butt welds, 0.35 for single-sided lap welds and 0.65 for double-sided lap welds. The allowable stress shall be two-thirds of the yield strength of the plate material.

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

- a) Cross-bracing in the plane of the roof surface shall be in at least two pairs of adjacent bays on all roofs exceeding 15 m diameter. Pairs of braced bays shall be spaced evenly around the tank circumference.
- b) Additional vertical ring bracing, on trussed roofs only, shall be provided in an approximately vertical plane between the trusses, as follows:
 - 1) 15 m < roof diameter ≤ 25 m: 1 ring;
 - 2) roof diameter > 25 m: 2 rings.

COMMENTARY AND RECOMMENDATIONS ON 7.1.5.3. *For coned roofs with plates of greater than minimum thickness and for domed roofs, the purlin spacing permitted may be increased by agreement between the purchaser and manufacturer.*

For roofs that are lapped, the lower edge of the uppermost plate should be beneath the upper edge of the lower plate to minimize the possibility of condensate entering the lap joint.

For roof plating outside the compression area, seams may be either butt welded or lap welded.

For roofs designed to be welded to the roof supporting structure, there should be adequate stiffness. It may not be necessary to include cross-bracing in accordance with 7.1.5.3, but care should be exercised during construction and before the welding is complete. Temporary cross-bracing should be fitted as necessary.

7.1.5.4 Roof plating without supporting structure

Roofs without supporting structure shall be of butt-welded or double lap-welded construction.

Roofs shall be checked for internal pressure and shall be designed to resist buckling due to external loading, as given by the following equations:

- a) *For internal pressure*

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

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

- b) *For buckling*

$$t_r = 40R_1 \left(\frac{10P_e}{E} \right)^{1/2}$$

where

R_1 is the radius of curvature of roof (in m) (for conical roofs = $R/\sin \eta$ [see Figure 6]);

P_e is the external loading (in kN/m²);

E is Young's modulus (in N/mm²);

p is the internal pressure [in mbar (gauge)];

S is the allowable design stress (in N/mm²) (see 7.1.4.1);

η is the joint efficiency factor (see 7.1.5.3);

t_r is the roof plate thickness (in mm).

7.1.5.5 Compression area

The compression area shall be in accordance with Figure 6 and shall be not less than that determined by the following equation:

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

where

A is the area required (in mm²);

p is the internal pressure, less weight of roof sheets [in mbar (gauge)];

θ is the slope of the roof meridian at roof-shell connection (in degrees) (see Figure 6);

R is the radius of the shell (in m);

S_c is the allowable compressive stress (in N/mm²). This shall be taken as 120 N/mm².

The effective compression area shall be made up of plates and/or sections where the maximum width is in accordance with Figure 6. Lap-welded roof plates shall not contribute to the compression area.

The compression area shall be proportioned such that the horizontal projection of the effective compression area has radial width of not less than 0.015 × the horizontal radius of the tank.

Additional compression area shall be provided by thickening the roof or shell plate, or by adding a bar or structural member, or by a combination of these. The additional compression area shall be arranged such that the centroid of the compression area falls within a vertical distance equal to 1.5 × the average thickness of the two members intersecting at the corner, above or below the horizontal plane through the corner.

The compression area shall be checked for tension loading due to external loads and/or internal negative pressure loading.

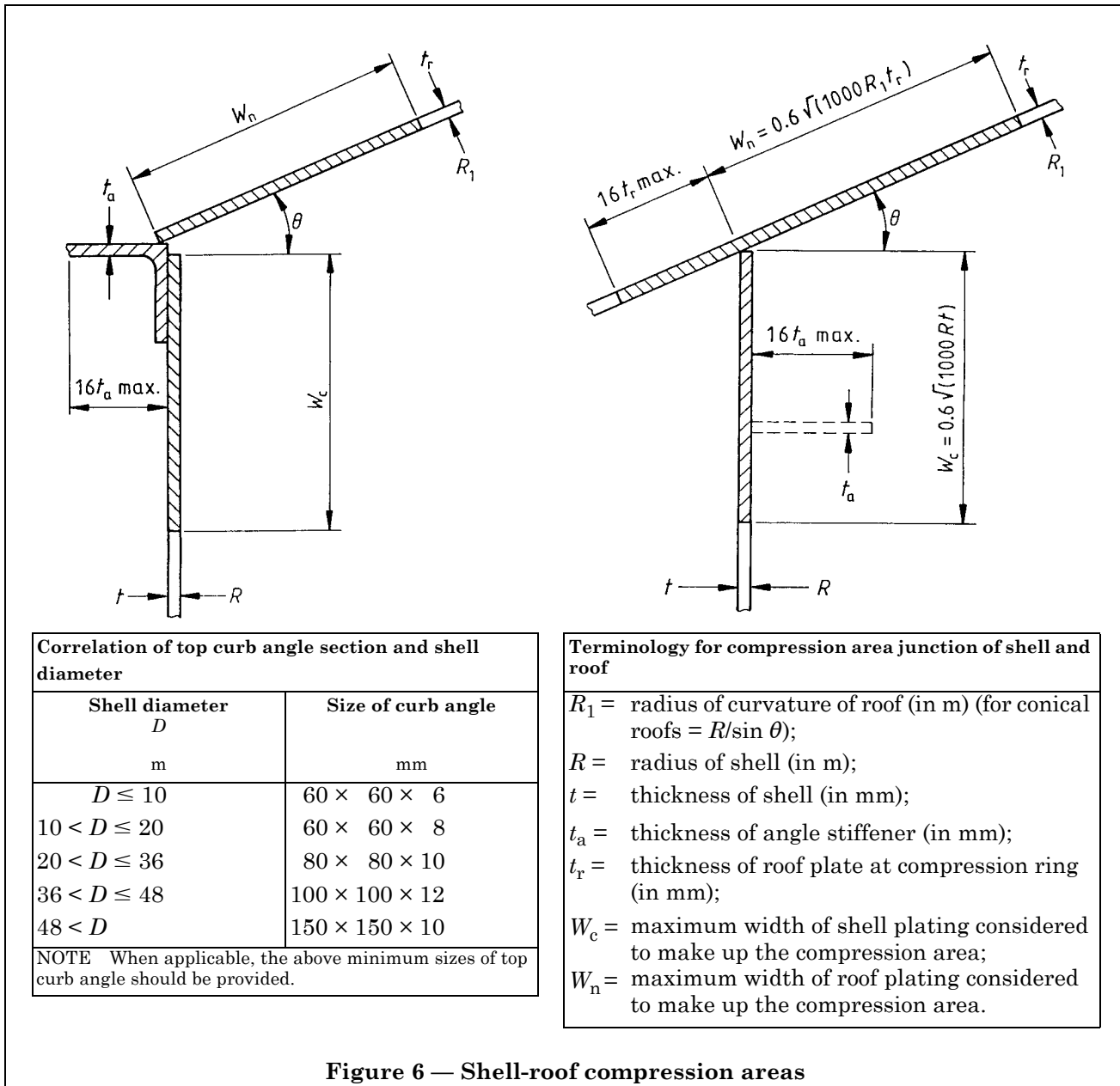


Figure 6 — Shell-roof compression areas

COMMENTARY AND RECOMMENDATIONS ON 7.1.5.5. *The compression area is the region at the junction of the shell and the roof that is considered to resist forces imposed by the internal pressure. The maximum widths of plates making up the compression region is indicated by the shaded area of Figure 6.*

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

Where different from 120 N/mm^2 , an allowable compressive stress should be agreed between the purchaser and the manufacturer.

7.1.6 Design of outer container mountings

7.1.6.1 General

The design of mountings attached to the outer container shall be in accordance with 7.1.6.2 to 7.1.6.10.

COMMENTARY AND RECOMMENDATIONS ON 7.1.6.1. *Openings in the outer shell or roof normally fulfil one of the following needs.*

- They provide entry or exit of personnel, insulation or purge medium to or from the interspace between inner tanks and outer containers.*

b) They provide entry or exit of personnel, product or vapour to or from the inside of the inner tank. Normally this also includes gauging devices that are sealed against vapour pressure.

For openings that are directly attached to the outer container, see 7.1.6; for other openings, see 7.2.7.

7.1.6.2 Shell manholes and shell nozzles 80 mm outside diameter and above

Shell manholes shall have a minimum diameter of 600 mm.

The thickness of the manhole or nozzle body shall be not less than that given in Table 9.

Table 9 — Manhole and nozzle body thickness

Outside diameter d_n mm	Minimum manhole and nozzle body nominal thickness t_p 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

Reinforcement shall be provided in accordance with either item a) or item b), as follows.

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

$$0.75 dt$$

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).

The maximum insert plate thickness shall be not greater than $2t$ (see Figure 7).

The corrosion allowance on any surface shall be excluded from the computation of reinforcement thickness.

b) The reinforcement shall be made by a thickened nozzle body protruding on both sides of the shell plate (see Figure 8). The thickness of the nozzle shall be determined such that the stress concentration factor (j) does not exceed 2 (see Figure 9).

COMMENTARY AND RECOMMENDATIONS ON 7.1.6.2.

Reinforcement can be provided by any one, or any combination of, the following three methods.

a) A thickened shell insert plate (see Figure 7 and Figure 20) or a circular reinforcing plate: the limit of reinforcement is such that:

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

where

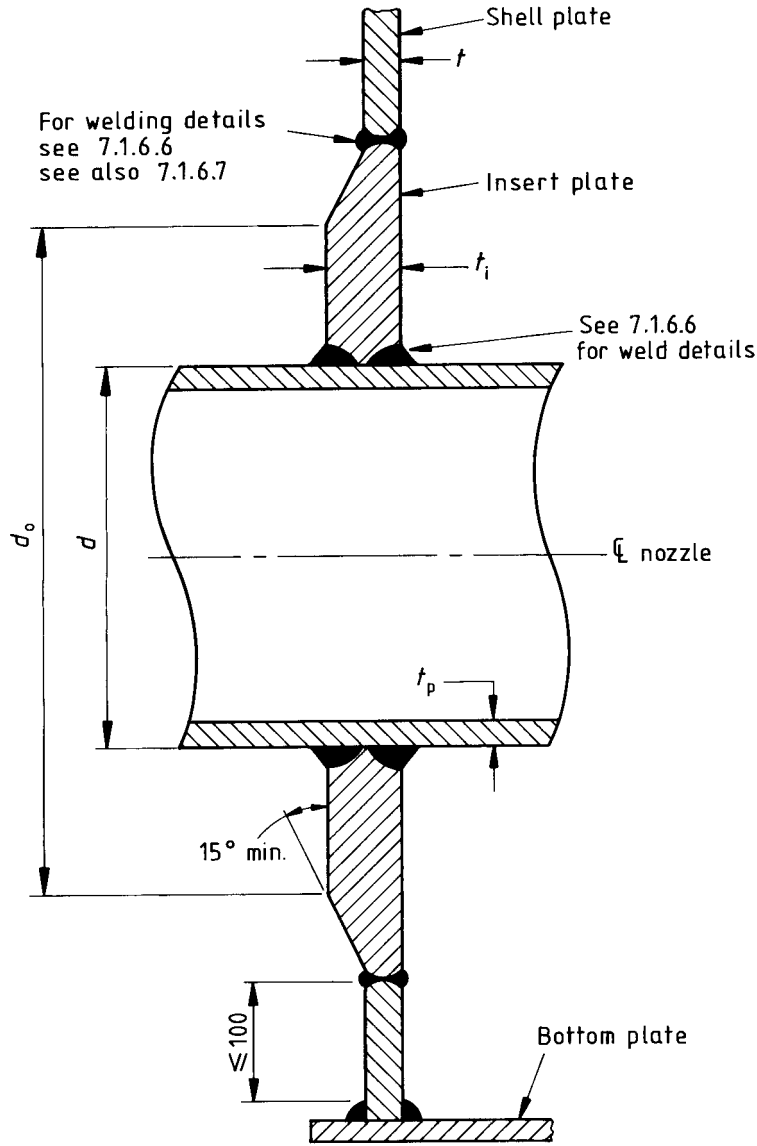
d_o is the effective diameter of reinforcement (in mm);

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

The limiting reinforcement should be met when a non-circular reinforcing plate is used.

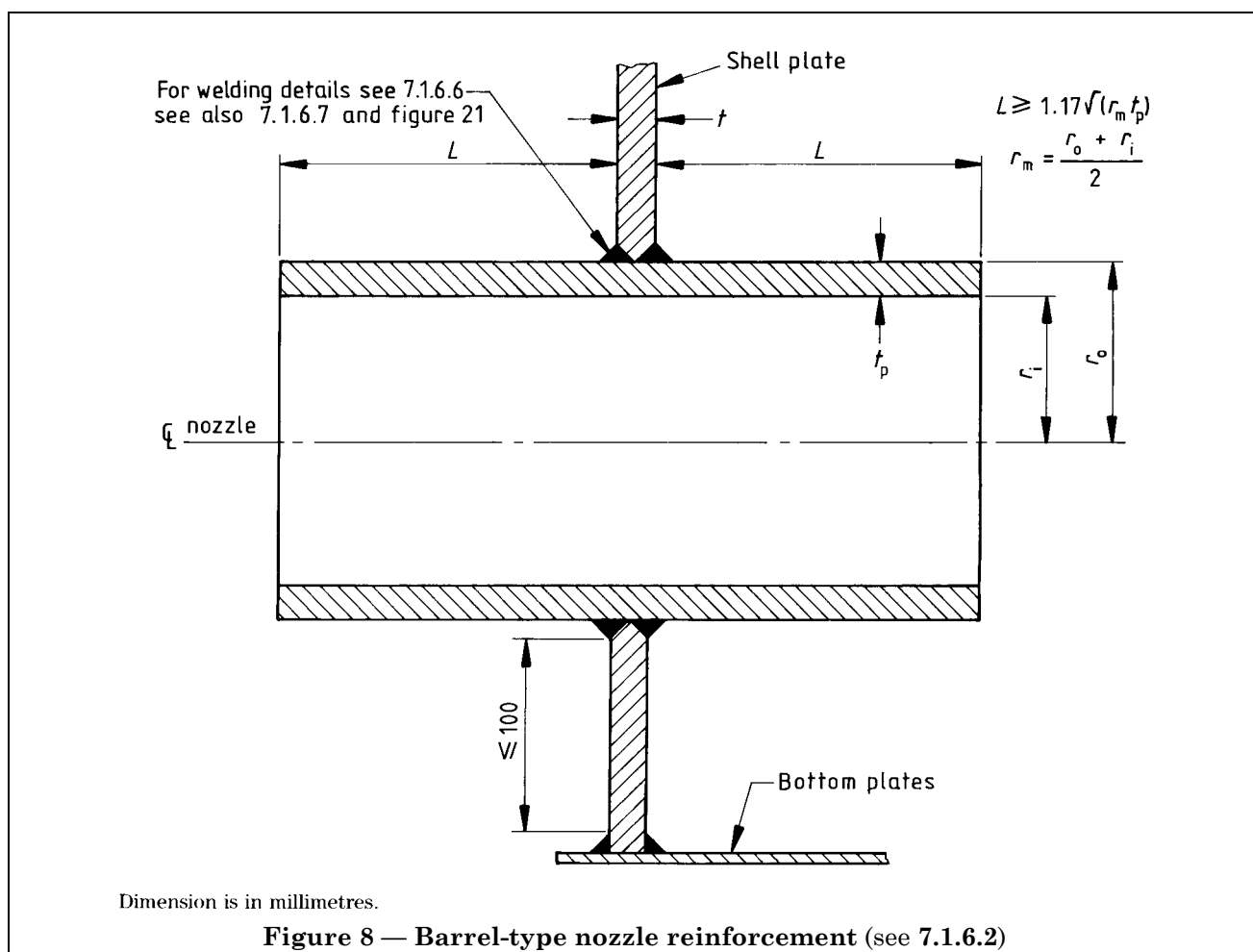
b) A thickened nozzle or manhole body: the portion of the body which may be considered as reinforcement is that lying within the shell plate thickness and within a distance of $4 \times$ the body thickness from the shell plate surface unless the body thickness is reduced within this distance, when the limit is the point at which the reduction begins.

c) A shell plate thicker than that of 7.1.4.2, and subject to the limits of 7.1.4.1: the limit of reinforcement is that of item a) of this recommendation.



Linear dimension is in millimetres.

Figure 7 — Shell-insert-type reinforcement (see 7.1.6.2)



7.1.6.3 Shell nozzles less than 80 mm outside diameter.

There shall be no additional reinforcement, provided that the thickness of the body is not less than that given in Table 9.

COMMENTARY AND RECOMMENDATIONS ON 7.1.6.3.
Set-on nozzles (see Figure 18) may be used, provided that the plates are checked close to the opening to ensure that no detrimental laminations are present. For this purpose, ultrasonic and/or magnetic-particle crack detection is recommended.

7.1.6.4 Roof manholes and nozzles

Roof openings shall be reinforced as for shell openings (see 7.1.6.2 and 7.1.6.3).

A roof manhole shall have a minimum inside diameter of 500 mm. It shall be suitable for attachment by welding to the tank roof plates.

The manhole covers shall be of the multiple-bolt fixed or hinged type.

Flanged nozzles for fixed-roof tanks shall be as shown in Figure 10.

7.1.6.5 Additional loads

Nozzles shall be designed to withstand the loads specified in Table 1 of BS 7777-1:1993.

7.1.6.6 Nozzle welding details

Weld details for nozzles, manholes and other openings shall be in accordance with Figure 11 to Figure 18. Standard weld details for the connection of mountings shall be as shown in Figure 19.

Partial penetration welds, as shown in Figure 11 and Figure 17 c, 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 190 N/mm².

The toes of fillet welds connecting a 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, or to the toe of the shell-to-bottom fillet weld, or to the toe of a fillet weld of an adjacent attachment.

The dimensions of the welds connecting set-through nozzles to the shell shall not be larger than twice the wall thickness of the mounting (see Figure 12 to Figure 17).

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 21).

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

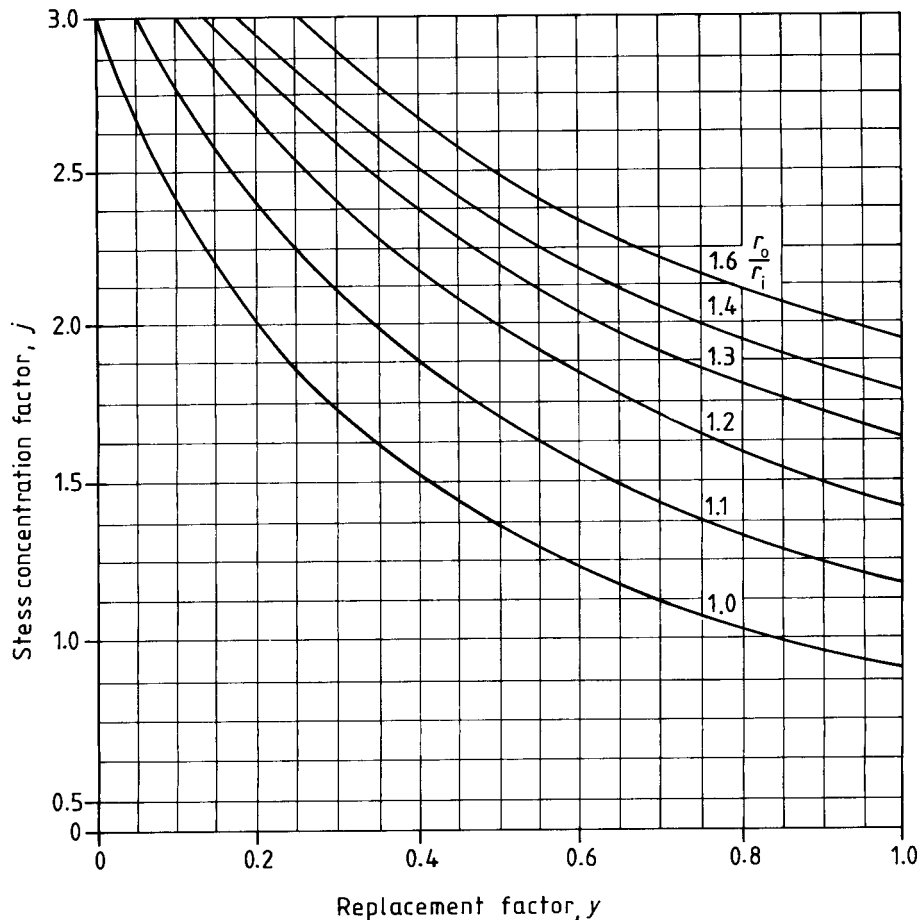
The leg length of fillet welds around the periphery of reinforcing plates shall equal the thickness of the reinforcing plate or 20 mm, whichever is less.

COMMENTARY AND RECOMMENDATIONS ON 7.1.6.6. *Other forms of joint preparation are permitted by agreement between the manufacturer and the purchaser.*

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 20).

With regard to Figure 11 to Figure 18 inclusive, and 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 should be substituted in the text when insert plates are used.

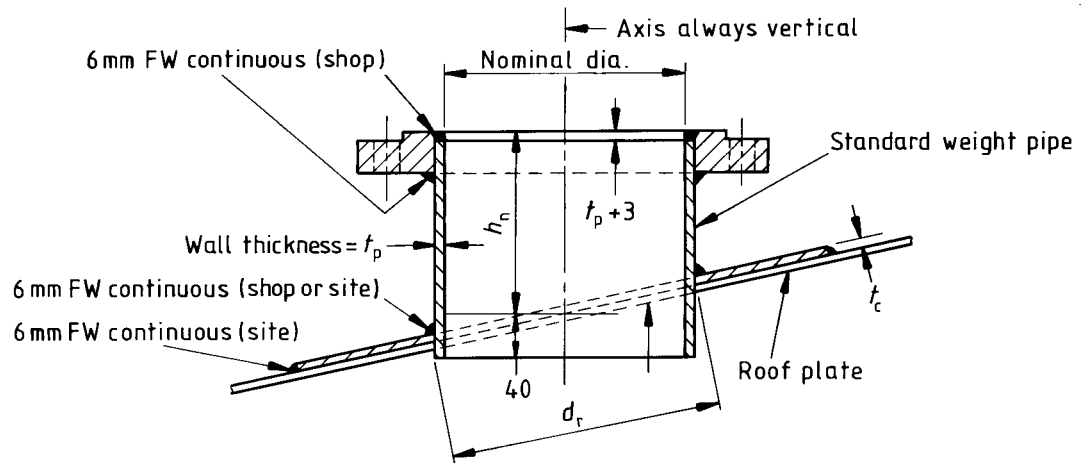
Reinforcing fillets should at least cover the penetration welds beneath.



$$y = 1.56 \left(\frac{t_p^3}{r_m t^2} \right)^{1/2} + \frac{t_p}{2r_m}$$

NOTE Reference should be made to R.T. Rose, Strength of rim reinforcements for manholes in welded storage tanks, *British Welding Journal*, October 1961[2].

Figure 9 — Graph for the determination of the thickness of a barrel-type nozzle reinforcement (see 7.1.6.2)



Dimensions are in millimetres.

Nominal diameter of nozzle		Outside diameter of pipe mm	Diameter of hole in roof plate d_r mm	Height of nozzle h_n mm
in	mm			
1	25	34	36.5	150
2	50	60	63.5	150
3	80	89	92.5	150
4	100	114	117.5	150
6	150	168	171.5	150
8	200	219	225.5	150
10	250	273	279.5	200
12	300	324	330.5	200

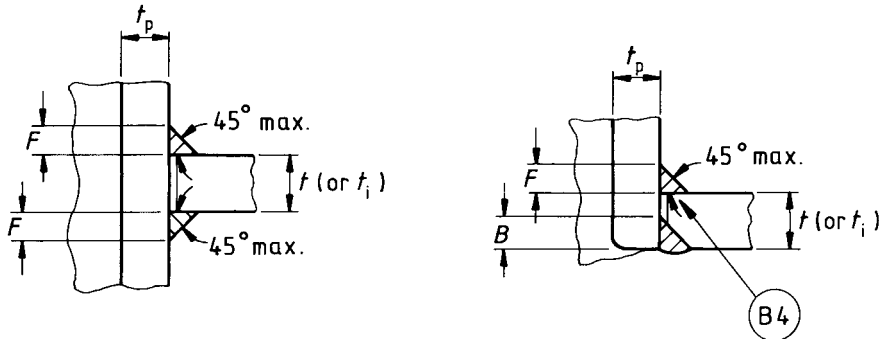
NOTE 1 Fillet weld (FW) sizes refer to leg lengths.

NOTE 2 When a roof nozzle is used for venting purposes, the neck may be trimmed flush with the reinforcing plate or roof line.

NOTE 3 The specification for roof manholes and nozzles should be agreed between the manufacturer and the purchaser.

NOTE 4 The dimensions of plate ring flanges should conform to class 150 of BS 1560-3.1 in all respects, except that the extended hub at the back of the flange may be omitted. Slip-on flanges conforming to class 150 (forged steel) may be substituted for plate ring flanges.

Figure 10 — Flanged roof nozzles (see 7.1.6.4)

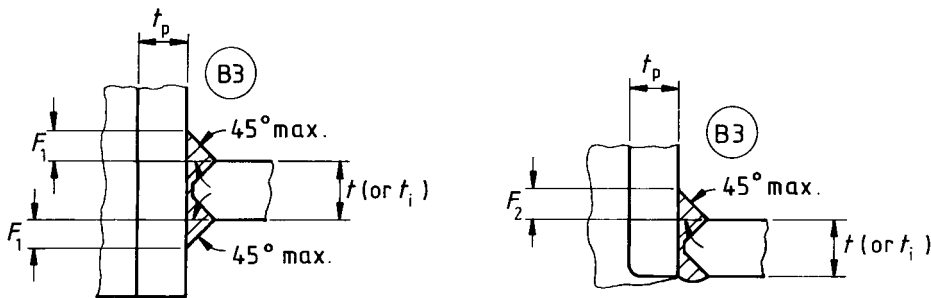


$F = B =$ lesser of t and t_p , with a minimum of 6 mm.

NOTE 1 For key to symbols, see Figure 7 and Figure 8.

NOTE 2 For standard weld details, see Figure 19.

Figure 11 — Weld details for connection of mountings: set-through type when $t = 20$ mm maximum and $t_p = 12.5$ mm maximum (preferred details)



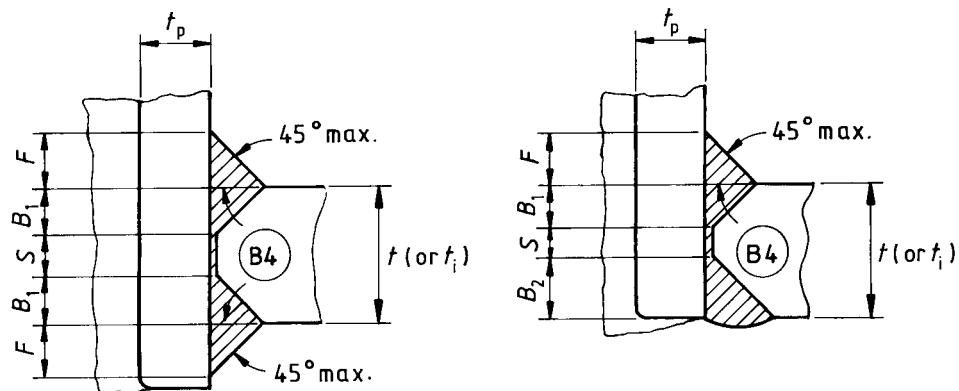
$F_1 =$ lesser of $t/2$ and $t_p/2$, with a minimum of 6 mm.

$F_2 =$ lesser of t and t_p , with a minimum of 6 mm.

NOTE 1 For key to symbols, see Figure 7 and Figure 8.

NOTE 2 For standard weld details, see Figure 19.

Figure 12 — Weld details for connection of mountings: set-through type when $t = 20$ mm maximum and t_p exceeds 12.5 mm (preferred details)



$F = 6$ mm minimum, 13 mm maximum.

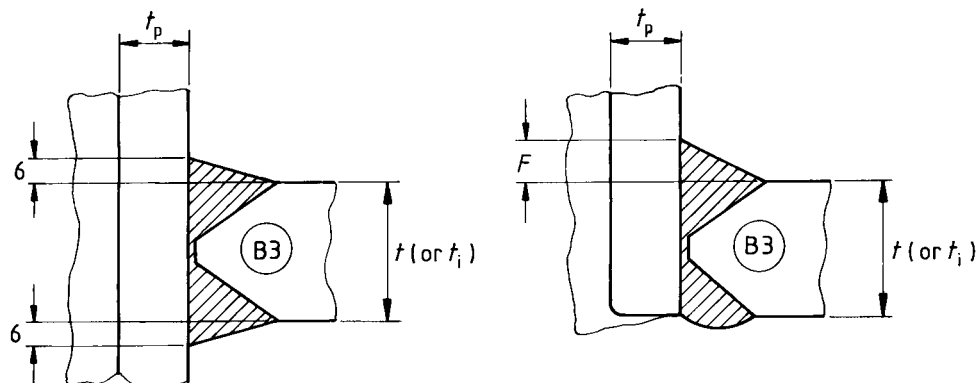
$$B_1 + F = t_p$$

$$B_2 = t_p$$

If B_1 or B_2 exceeds 16 mm, use J-type weld detail.

If S is less than 3 mm, use details c) and d) as appropriate.

a) When $t_p = 12.5$ mm maximum



$F = t/4$, but not less than 6 mm.

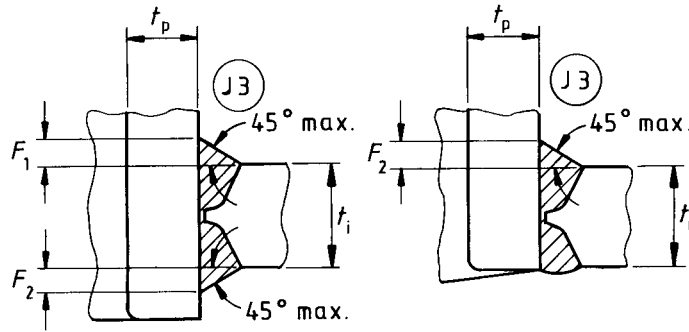
If t exceeds 30 mm, use J3 weld detail.

b) When t_p exceeds 12.5 mm.

NOTE 1 For key to symbols, see Figure 7 and Figure 8.

NOTE 2 For standard weld details, see Figure 19.

Figure 13 — Weld details for connection of mountings: set-through type when $20 \text{ mm} \leq t \leq 40 \text{ mm}$ (preferred details)



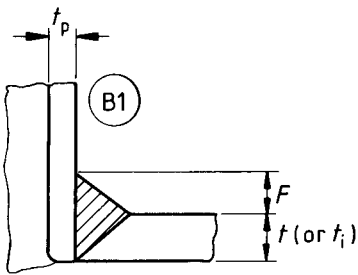
$F_1 = t_i/8$ minimum, but not less than 6 mm.

$F_2 = t_i/4$ minimum, but not less than 13 mm.

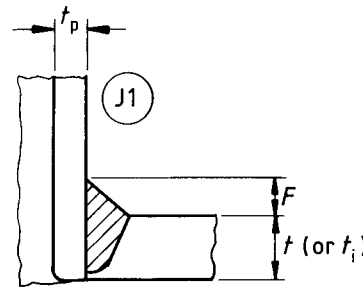
NOTE 1 For key to symbols, see Figure 7 and Figure 8.

NOTE 2 For standard weld details, see Figure 19.

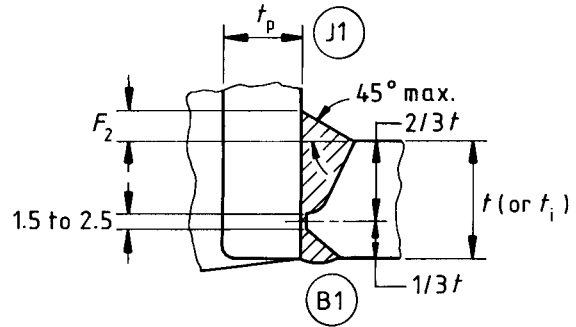
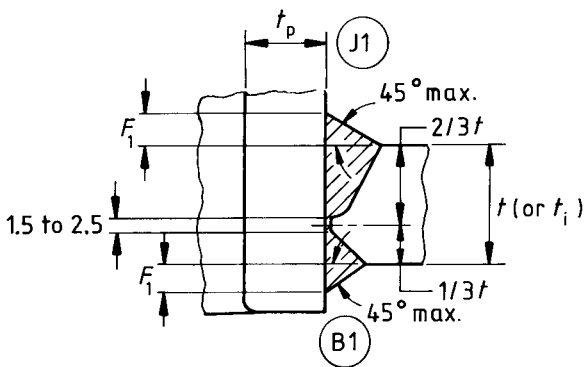
Figure 14 — Weld details for connection of mountings: set-through type when $t_i > 40$ mm (preferred details)



a) When $t = 16$ mm maximum



b) When $t = 25$ mm maximum



Linear dimensions are in millimetres.

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

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

If t_i exceeds 50 mm, use J1 detail both sides.

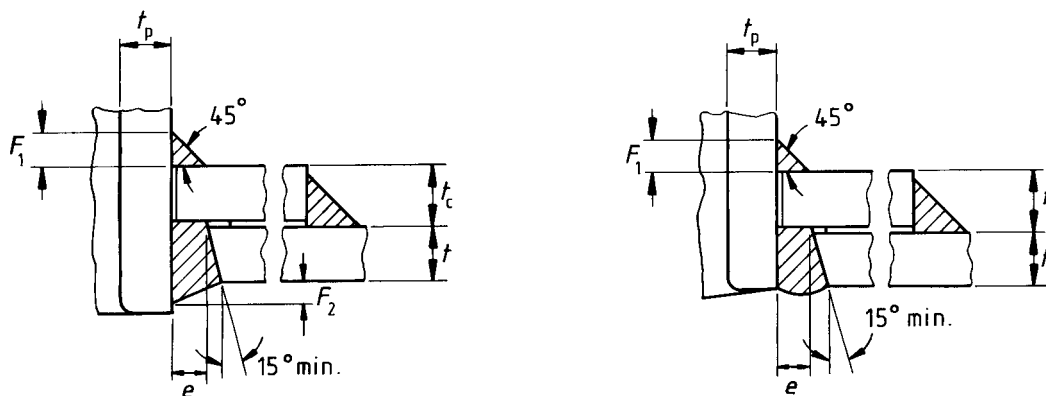
c) When t exceeds 20 mm and t_p exceeds 12.5 mm

NOTE 1 For key to symbols, see Figure 7 and Figure 8.

NOTE 2 For standard weld details, see Figure 19.

NOTE 3 For details a) and b), where $t_p \geq 16$ mm, the root should be back gouged to sound metal and welded.

Figure 15 — Weld details for connection of mountings: set-through type (alternative details)



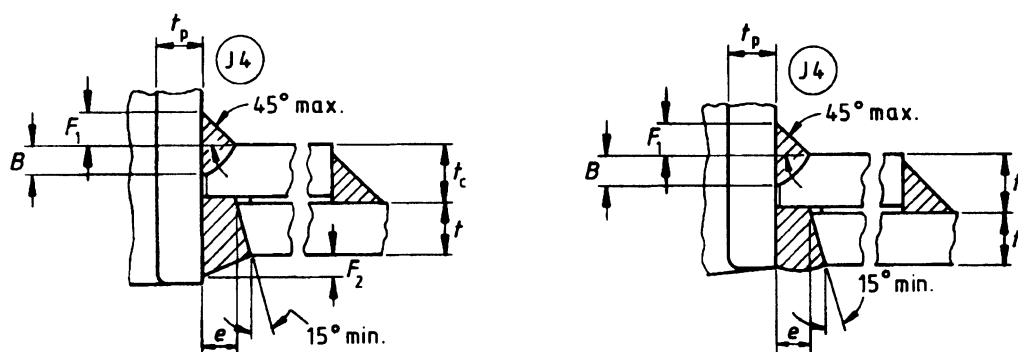
F_1 = lesser of t_p and t_c , with a minimum of 6 mm.

e = 10 mm minimum to 20 mm maximum as required for access.

F_2 = $t_p/3$ minimum but not less than 6 mm.

NOTE For key to symbols, see Figure 7, Figure 8 and Figure 10.

Figure 16 — Weld details for connection of mountings: compensated set-through type (preferred details)



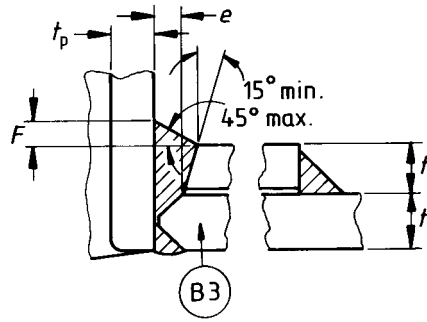
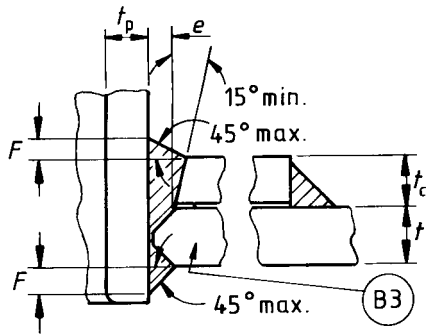
$B + F_1$ = lesser of t_p and t_c .

F_1 = 6 mm minimum.

e = 10 mm minimum to 20 mm maximum as required for access.

a) F_2 = $t_p/3$ minimum but not less than 6 mm.

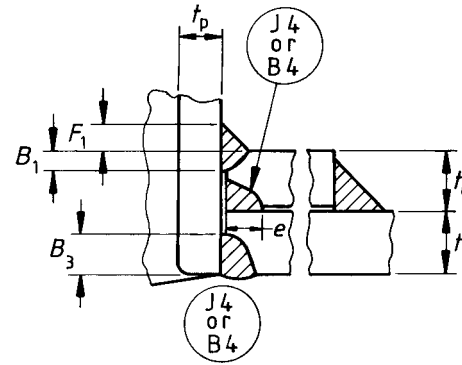
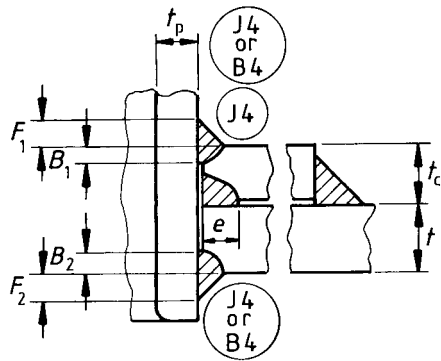
Figure 17 — Weld details for connection of mountings: compensated set-through type (alternative details)



$F = t_p/3$ minimum but not less than 6 mm.

$e = 10$ mm minimum to 20 mm maximum as necessary for access.

b)



$t = 12.5$ mm maximum.

$B_1 + F_1 = e =$ lesser of t_p and t_c , with a minimum of 6 mm.

$(B_2 + F_2)$ or $B_3 =$ lesser of t_p and t , with a minimum of 6 mm.

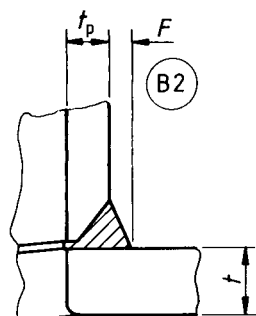
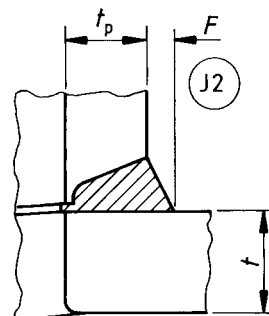
c)

NOTE 1 For key to symbols, see Figure 7, Figure 8 and Figure 10.

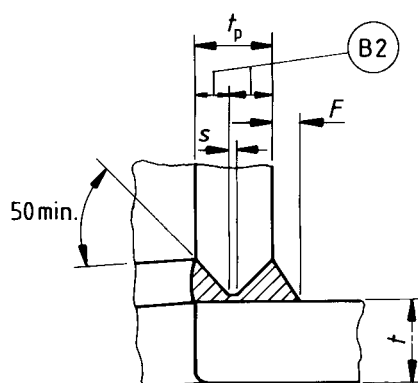
NOTE 2 For standard weld details, see Figure 19.

NOTE 3 These details are alternative to those shown in Figure 16.

Figure 17 — Weld details for connection of mountings: compensated set-through type (alternative details) (concluded)

a) When $t_p = 16$ mm maximum

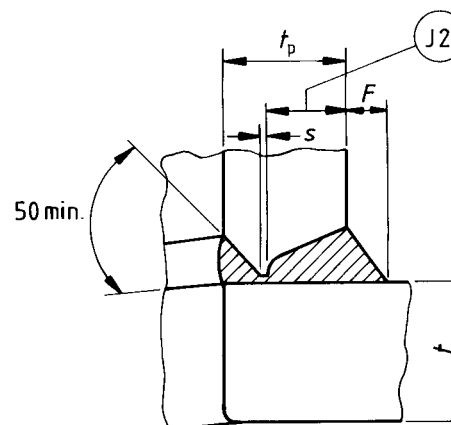
$$F = t_p/3.$$

b) When t_p exceeds 16 mm

$$F = t_p/3 \text{ minimum but not less than 6 mm.}$$

$$S = 1.5 \text{ mm to 2.5 mm.}$$

c) When the bore of the nozzle is accessible for welding



$$F = t_p/3 \text{ minimum less than 6 mm.}$$

$$s = 1.5 \text{ mm to 2.5 mm.}$$

NOTE 1 For key to symbols, see Figure 7 and Figure 8.

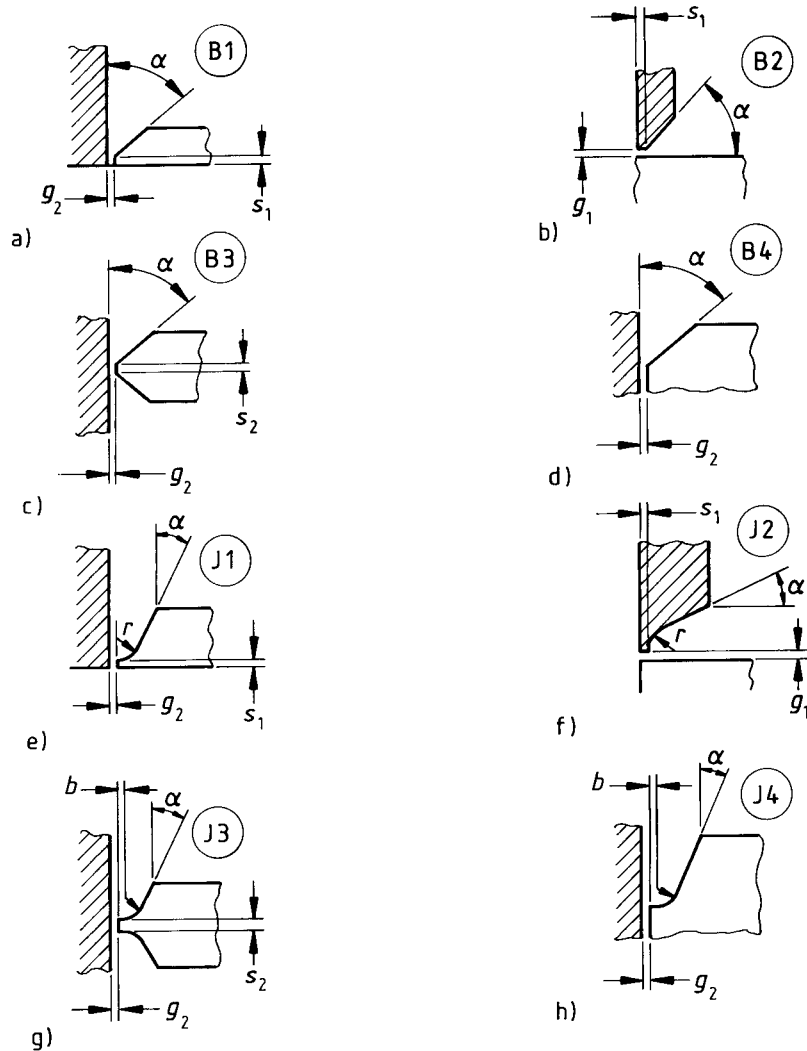
NOTE 2 For standard weld details, see Figure 19.

NOTE 3 For set-on nozzles, the shell plate should be examined for laminations around the branch hole.

NOTE 4 If the welding procedure does not ensure sound positive root penetration, joints should be back chipped or gouged and back welded. The internal penetration bead of joints welded from one side only should be ground smooth and flush with the inside bore.

NOTE 5 Details c) and d) are given for where the bore of the nozzle is readily accessible for welding. The joint should be back gouged from the side most accessible and suitable for the purpose, but generally the outside.

Figure 18 — Weld details for connection of mountings: set-on type

**Key to details a) to d)**

$\alpha = 50^\circ$ minimum.
 $s_1 = 1.5 \text{ mm to } 2.5 \text{ mm}$.
 $s_2 = 0 \text{ mm to } 3 \text{ mm}$.
 $g_1 = 2.5 \text{ mm to } 3 \text{ mm}$.
 $g_2 = (\text{note 2 applies})$.

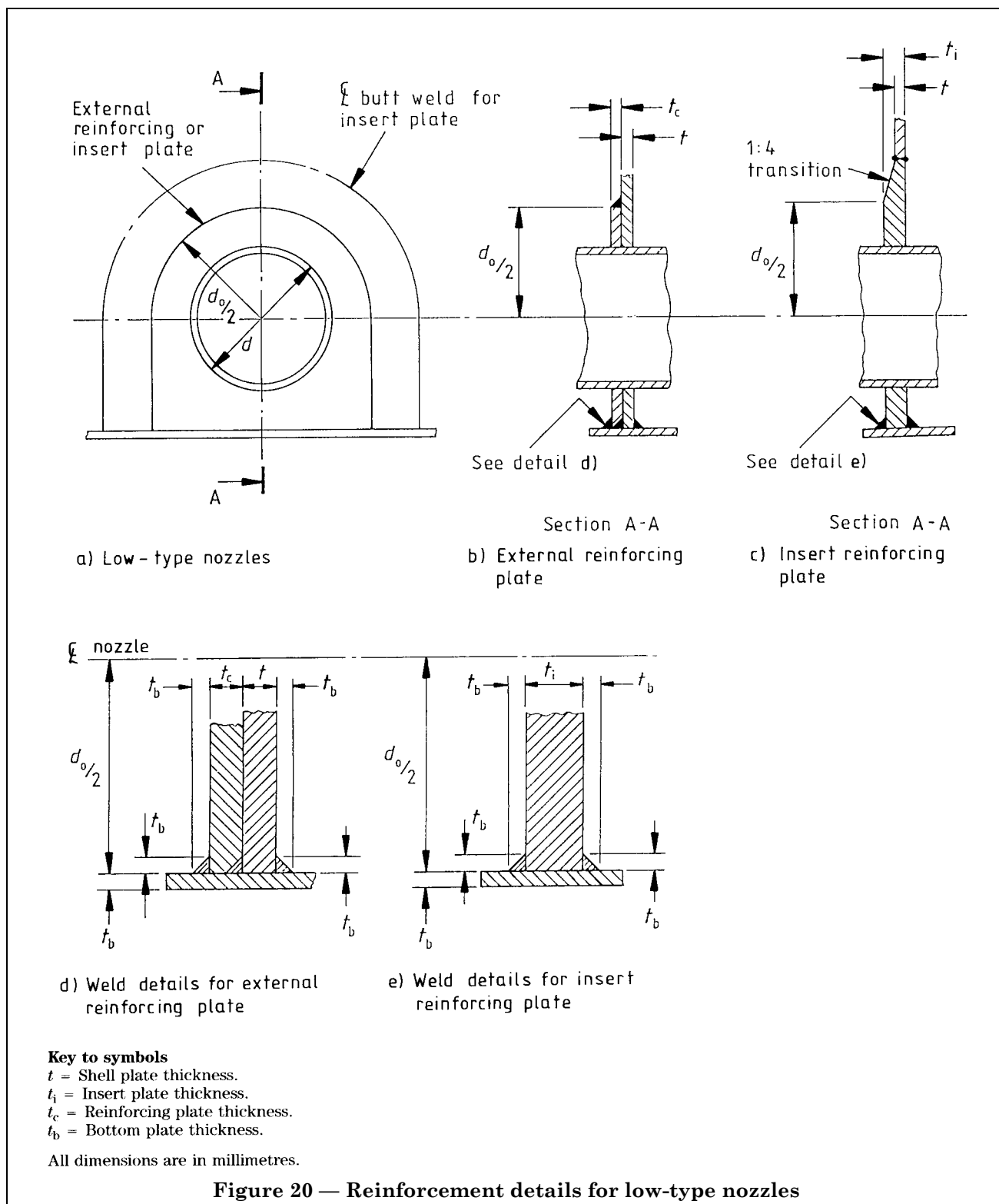
Key to details e) to h)

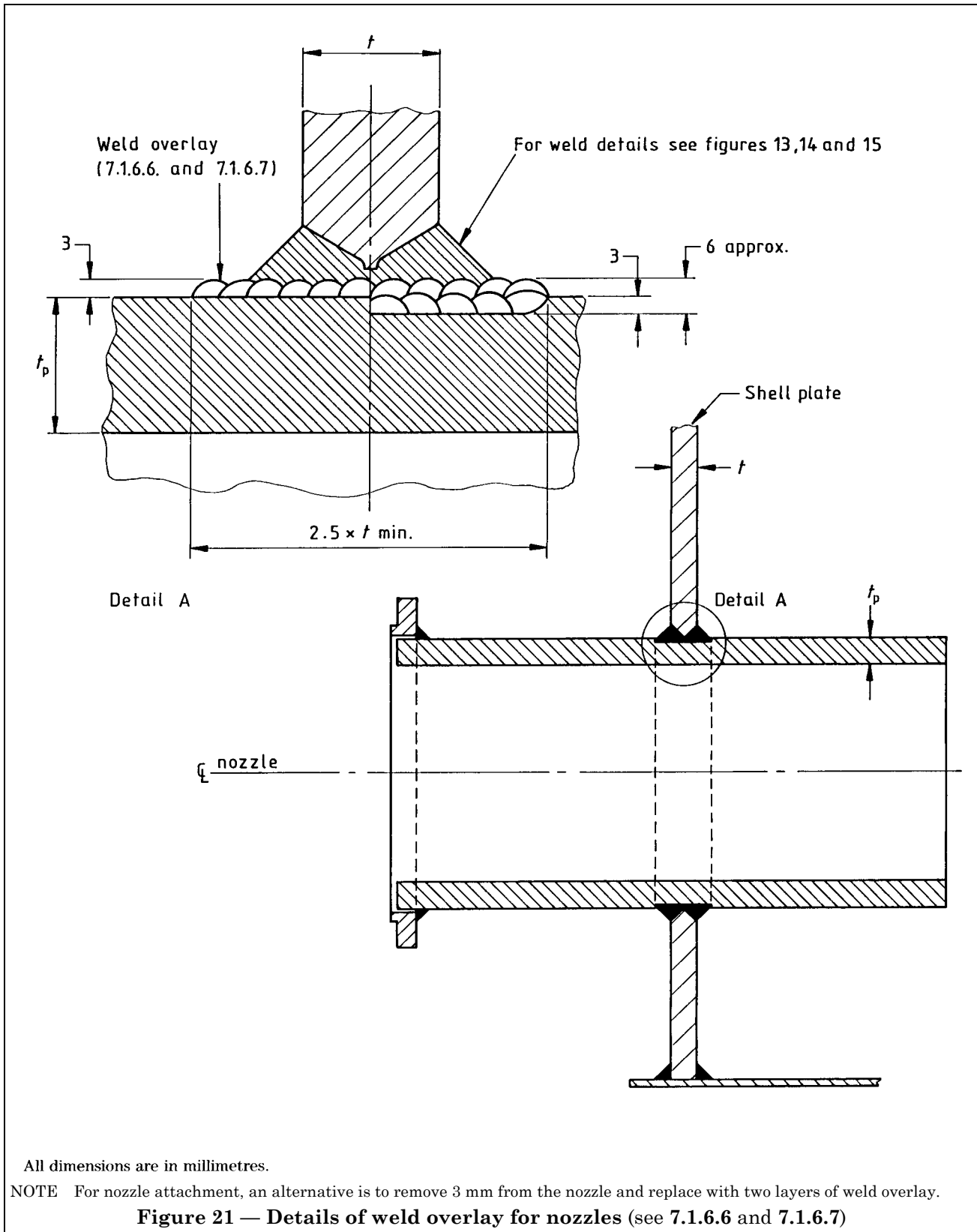
$\alpha = 15^\circ \text{ to } 35^\circ$.
 $s_1 = 1.5 \text{ mm to } 2.5 \text{ mm}$.
 $s_2 = 3 \text{ mm to } 4.5 \text{ mm}$.
 $g_1 = 1.5 \text{ mm to } 3 \text{ mm}$.
 $g_2 = (\text{note 2 applies})$.
 $b = 0 \text{ mm to } 3 \text{ mm}$.
 $r = 6 \text{ mm to } 13 \text{ mm}$.

NOTE 1 For these details, discretion should be used in applying the maximum and the minimum dimensions quoted, since they are subject to variation according to the welding procedure employed (e.g. size and type of electrodes). Further, the position in which the welding is carried out, and the welding process adopted, should be considered carefully.

NOTE 2 It is considered that in 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 joined parts increases.

Figure 19 — Standard weld details for connection of mountings





7.1.6.7 Inspection of shell nozzles and manholes

Butt welds connecting insert plates to the shell plate shall be 100 % radiographed. All fillet welds and butt welds that cannot be examined by radiography shall be fully magnetically crack detected before the pressure test.

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 for laminations.

COMMENTARY AND RECOMMENDATIONS ON 7.1.6.7.

Surface irregularities that may confuse or mask any defect should be carefully removed.

7.1.6.8 Flange drilling

The flanges of all nozzles and manholes shall be made and drilled in accordance with the requirements for class 150 flanges of BS 1560-3.1:1989.

COMMENTARY AND RECOMMENDATIONS ON 7.1.6.8.

Flanges may be made from plate. They should be shown by calculation to be suitable for the design conditions and to provide leak tight joints.

7.1.6.9 Access to the tank or container roof

Means of access to the roof shall be provided by one of the following.

- a) A gangway from an adjacent tank or item of plant.
- b) A tower stairway which may also be used to support pipework and other services to the roof.
- c) A spiral stairway supported by an outer shell. This shall only be permitted for steel outer containers.

Design of structural steelwork associated with tank access shall be in accordance with BS 449-2:1969 or BS 5950.

COMMENTARY AND RECOMMENDATIONS ON 7.1.6.9.

Other forms of access, such as stairways around tubular columns, should be by agreement between the purchaser and the contractor.

7.1.6.10 Stairways and gangways

Stairways and gangways shall be of metallic construction and the minimum clear width shall be 600 mm.

Stairway angle to the horizontal plane shall not exceed 42°.

Stairways shall be of the double stringer type (see 7.1.6.9).

Stairway treads, landings and gangways shall be galvanized, non-slip, rectangular mesh type in accordance with BS 4592.

Stairway treads shall have a maximum rise of 200 mm. Successive treads above should overlap the lower tread by a minimum of 16 mm, measured at the centre line of the stairway, and have a nosing depth in the range 25 mm to 50 mm.

Stairways and gangways shall be capable of supporting a superimposed load of 2.4 kN/m².

Where the vertical rise of stairways exceeds 6 m, an intermediate landing (or landings) shall be provided with a minimum length of 900 mm.

Access to roof fittings shall be by stairways and gangways supported from the tank roof.

Toe boards shall be provided at gangways, platforms and roof peripheries where peripheral handrailing is provided. They shall consist of a 150 mm × 6 mm flat installed with a 10 mm gap beneath the lower edge of the flat.

Tank gangways that extend from one tank to an adjacent tank, or to the ground or to any other structure, shall be supported in such a way as to permit free relative movement of the structures joined by the gangway.

COMMENTARY AND RECOMMENDATIONS ON 7.1.6.10.

For conical roof tanks, where the roof slope does not exceed 1 in 5, and there is no external roof insulation, access to roof fittings may be by treads welded directly to the roof plating, with handrailing on both sides (see Figure 22).

7.1.6.11 Handrailing

Handrailing shall be provided on the outer side of a spiral stairway. Handrailing shall be provided on both sides of a gangway and/or stairway, and on a spiral stairway where the distance between either the shell or the outside of the shell insulation and the stairway inner stringer exceeds 200 mm.

Handrailing shall be of solid or tubular steel with a minimum diameter of 30 mm. Handrail stanchions shall be of the solid forged type or angle section and shall be spaced around the periphery of a roof, on gangways, platforms and stairways (measured along the slope of the stairway), at a distance not exceeding 1.8 m.

Handrailing shall be capable of resisting a uniformly distributed horizontal load of 750 N per metre run applied to the top of the handrail.

COMMENTARY AND RECOMMENDATIONS ON 7.1.6.11.

Where the roof slope exceeds 1 in 5, consideration should be given to the provision of a higher standard of handrailing around the periphery.

Handrailing should be provided around the whole of the periphery. In some instances, however, it may only be necessary to provide handrailing around part of the periphery.

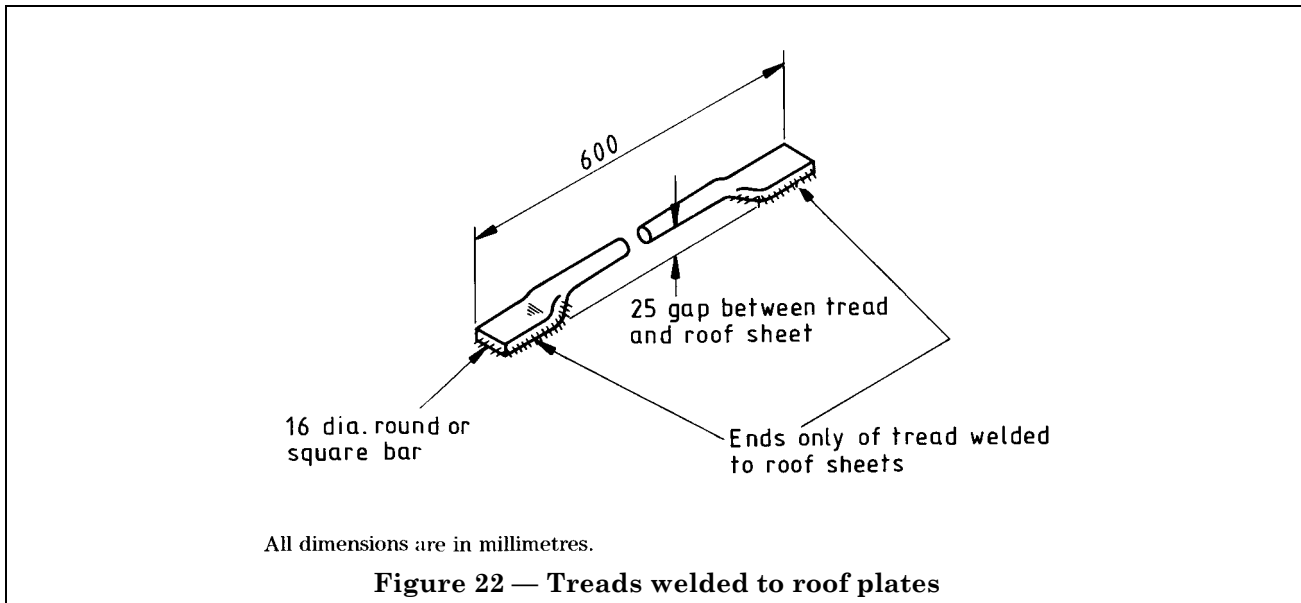


Figure 22 — Treads welded to roof plates

Particular care should be taken in the jointing of handrailing to ensure the full strength of the members.

7.1.6.12 Ladders

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

If the height of the ladder exceeds 6 m, an intermediate landing shall be provided.

Ladders shall be designed to carry a suspended load of 2 kN.

COMMENTARY AND RECOMMENDATIONS ON 7.1.6.12.

Ladders may be considered for both the inside and outside of tanks.

The line of a ladder should preferably be broken at an intermediate platform.

There should be a minimum clearance of 230 mm between the centre line of the rungs and the nearest structure.

7.1.6.13 Earthing connections

All tanks or containers shall be fitted with suitable earthing connections (see Figure 23).

7.1.6.14 Anchorage

For information on anchorages, see 7.2.9.

7.2 Inner tank of double shell single containment tank

COMMENTARY AND RECOMMENDATIONS ON 7.2. An illustration of the inner tank of a double shell single containment tank is given in Figures 1c and 1d of BS 7777-1:1993.

7.2.1 Inner tank materials

Materials to be used in the manufacture of inner tanks shall be in accordance with clause 6.

7.2.2 Inner tank loadings

The inner tank loadings shall be in accordance with Table 1 of BS 7777-1:1993.

7.2.3 Inner tank bottom

7.2.3.1 General

Bottom and annular material shall be the same type as that for the shell (see clause 6).

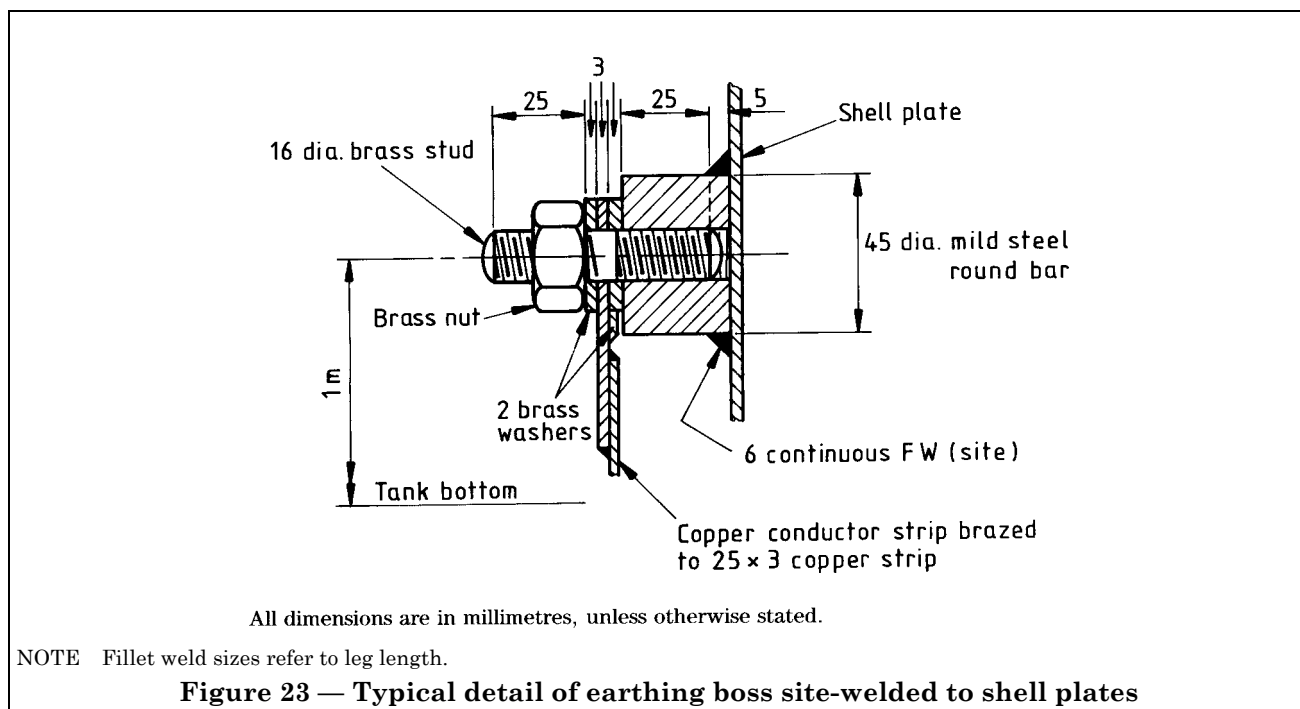
The tank bottom shall have a ring of annular plates under the shell in accordance with Figure 1. The minimum width of annular plates shall be 650 mm. The joints between these plates shall be butt welded. Other bottom plates shall be lap and/or butt welded.

The minimum nominal thickness of bottom plates shall be 6 mm.

The minimum thickness of annular plates shall be in accordance with Table 10.

Table 10 — Minimum thickness of annular plate

Bottom course shell plate thickness t_1 mm	Minimum annular plate thickness mm
$t_1 \leq 19$	The lesser of 8 mm or t_1
$19 < t_1 \leq 32$	10
$32 < t_1$	12.5



7.2.3.2 Bottom design

Lap joints shall have a minimum overlap of $5 \times$ the thickness of the plate and shall be welded on the top side only.

For all materials, the fillet welds on the top side shall consist of at least two passes of welding.

At the ends of cross joints, in lap-welded plates where three thicknesses occur, the upper plate shall be fitted and welded as indicated in Figure 2.

Butt welds in annular, sketch or bottom plates shall be welded either from both sides, or from one side using a backing strip.

The attachment between the bottom edge of the lowest course of shell plates and the annular plates shall be fillet welded continuously on both sides of the shell plate. Each fillet weld shall consist of at least two passes. The leg length of each fillet weld shall be equal to the thickness of the annular plate.

COMMENTARY AND RECOMMENDATIONS ON 7.2.3.2.

Where a full penetration weld is used between the lowest course and the annular plate, additional distortion might occur.

7.2.4 Inner tank shell

7.2.4.1 Design stresses

The maximum allowable stress in any plate or weld under hydrostatic test shall be limited to 85 % of the specified minimum yield or proof strength of the parent plate or weld metal, whichever is lower, but in no case shall it exceed 340 N/mm^2 .

The maximum allowable design stress in service of any plate or weld shall be the lowest value determined from Table 11, but in no case shall it exceed 260 N/mm^2 .

Table 11 — Determination of the maximum allowable design stress

Carbon-manganese steels	UTS/2.35 or YS/1.5
Improved toughness carbon manganese steels	UTS/2.35 or YS/1.5
Low nickel steels	UTS/2.35 or 0.2 % PS/1.5
9 % nickel steel	UTS/2.35 or 0.2 % PS/1.5
Austenitic stainless steels	UTS/2.5 or 1% PS/1.5

The ultimate tensile stress (UTS), proof stress (PS) and yield stress (YS) as specified in this clause and in Table 11 shall be the minimum specified or the guaranteed value given at room temperature in the appropriate material specification for the parent plate. In the case where the weld metal strength values are less than the parent plate strength values, the weld metal tensile and proof strengths used shall be those demonstrated to have been achieved when tested in accordance with the tensile test of 11.12.3.

7.2.4.2 Shell plate thickness

For construction purposes, the minimum shell thickness shall be in accordance with Table 12. The maximum shell thickness shall be in accordance with 6.1.2.

Table 12 — Minimum shell plate thickness

Tank diameter D m	Minimum shell thickness mm
$D < 30$	8
$30 \leq D < 50$	10
$50 \leq D$	12

NOTE This thickness may include any corrosion allowance provided that the shell is shown by calculation to be safe in the corroded condition and in accordance with the requirement of 7.2.4.3.

7.2.4.3 Internal loading

The forces in the tank shell shall be calculated assuming that the tank is filled to the maximum specified product level and taking into account the superimposed design roof pressure. The maximum specified product level shall be not higher than 0.5 m below the top of the shell (see 7.2.3 of BS 7777-1:1993).

The thickness of the shell plate shall be taken as the greater of t_t or t , as determined from either the equation in item a) or the equation in item b) as appropriate.

a) The following equation is used for calculating the thickness of shell plates under test conditions:

$$t_t = \frac{D}{20S_t} \{98W_t(H - 0.3) + P_t\}$$

where

- t_t is the calculated minimum plate thickness (in mm);
- H is the height from the bottom of the course under consideration to the highest liquid level (in m);
- D is the tank inside diameter (in m);
- W_t is the maximum density of the test water (in g/ml);
- S_t is the allowable stress under test conditions (in N/mm²) (see 7.2.4.1);
- P_t is the test pressure and is equal to zero in the case of an inner tank with no attached roof [in mbar (gauge)].

b) The following equation is used for calculating the thickness of shell plates under product conditions:

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

where

- t is the calculated minimum plate thickness (in mm);
- H is the height from the bottom of course under consideration to the highest liquid level (in m);
- D is the tank inside diameter (in m);
- W is the maximum density of the liquid under storage conditions (in g/ml);
- S is the allowable design stress (in N/mm²) (see 7.2.4.1);
- P is the design pressure and is equal to zero in the case of an inner tank with no attached roof [in mbar (gauge)];
- c is the corrosion allowance (in mm).

The tensile force in each course shall be calculated at 300 mm above the centre line of the horizontal joint in question. No course shall be constructed at a thickness less than that of the course above, irrespective of materials of construction.

The inner tank shall be hydrostatically tested to a level equal to the maximum specified product level (see 7.2.5 of BS 7777-1:1993).

COMMENTARY AND RECOMMENDATIONS ON 7.2.4.3. *The ullage for earthquake sloshing need not be included in the design product level. The compression area at the top of the shell can be thicker than the shell plate of the tier below.*

7.2.4.4 Design for external loading

The tank shell shall include stiffening to maintain roundness and to prevent buckling under negative differential pressure and pressure exerted by the insulation.

COMMENTARY AND RECOMMENDATIONS ON 7.2.4.4. *Loose powder insulants, used for filling the interspace between the inner and outer shells, exert an external pressure on the inner shell of a magnitude depending on:*

- a) the resilience of the powder and any resilient cushion included in the insulation system;
- b) the characteristics of the powder such as angle of repose and coefficient of friction, and external pressure;
- c) the number of thermal cycles and their magnitude;

d) the configuration of the annular space and the height of the shell at the point of consideration.

After making allowance for the accuracy in the determination of the design external pressure, horizontal ring stiffeners are required where pitch is determined in accordance with 7.1.4.3. An assumed value for V_a (mbar) as $2 \times$ the value determined from the criteria above, should be used.

Each horizontal ring stiffener should be designed for the panel loading associated with that ring, taking into account that portion of the shell considered to contribute to the stiffness of the ring and the stiffness characteristics of the insulation system.

7.2.4.5 Design for thermal loading

COMMENTARY AND RECOMMENDATIONS ON 7.2.4.5. The effect of the transient thermal conditions during cool-down and warm-up, as well as those that occur during service, should be considered.

7.2.4.6 Shell plate arrangement

The tank shall be designed such that all courses are vertical and the diameter on the centre line of each course is equal to the nominal diameter of the tank.

COMMENTARY AND RECOMMENDATIONS ON 7.2.4.6. The distance between vertical joints in adjacent courses should be not less than one-third of the plate length, but in no case less than 150 mm.

Where the distance between vertical joints is less than one-third plate length, additional precautions may be necessary to prevent undue distortion.

7.2.4.7 Shell joints

Vertical seams shall be butt joints, with full penetration and complete fusion.

Horizontal seams shall be butt joints and, for a distance of 150 mm at either side of each vertical seam T-junction, shall have full penetration and complete fusion. The procedure used for welding portions of the girth seams between the T-junctions shall be as qualified in welding approval tests (see 11.12).

COMMENTARY AND RECOMMENDATIONS ON 7.2.4.7. It is recognized in practice that continuous full penetration for the welding of horizontal joints may not always be achieved between T-junctions. This need not necessarily be a 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.

Rigorous rectification of a lack of full penetration in horizontal joints should be avoided, since repair welds may not improve the integrity of the tank.

7.2.5 Inner tank roof design

7.2.5.1 Types of roof

The roof shall be one of the following types:

- roof plating with supporting structure;
- roof plating without supporting structure;
- reinforced membrane roof;
- suspended deck, supported from outer tank roof.

COMMENTARY AND RECOMMENDATIONS ON 7.2.5.1. Where a dome roof is adopted, the radius of curvature should be the subject of agreement between the purchaser and the manufacturer. The radius should normally be in the range of 0.8 to $1.5 \times$ the diameter of the tank shell.

7.2.5.2 Compression area

Compression area shall be provided (see 7.1.5.5).

7.2.5.3 Roof plating with supporting structure

The roof shall be designed, and the plate thickness shall be checked, in accordance with 7.1.5.3.

COMMENTARY AND RECOMMENDATIONS ON 7.2.5.3. BS 449 or BS 5950 specify allowable design stresses for steels manufactured in accordance with BS EN 10025 or BS 4360.

For other materials permitted by this standard for the inner tank, the allowable design stresses are to be agreed between the purchaser and the manufacturer.

7.2.5.4 Roof plating without supporting structure

The roof shall be designed in accordance with 7.1.5.3 and 7.1.5.4.

COMMENTARY AND RECOMMENDATIONS ON 7.2.5.4. Where reinforced membrane roofs are used, special calculations may be necessary.

7.2.5.5 Suspended decks

A suspended deck support structure shall be designed for the lowest temperature encountered in practice, of any section under consideration. The design shall ensure that the outer roof shall always be at ambient temperature where support hangers are attached to it.

The structure shall be designed to allow for any one hanger rod or rope becoming ineffective.

Materials for suspended decks shall be agreed between the purchaser and the manufacturer.

A suspended deck shall be so insulated that the outer roof does not cool below its design metal temperature, that the boil-off of the product is controlled and that ice-formation leading to excessive roof loads is prevented. The system of insulation and support structure shall be designed to prevent passage of insulation into the stored product, but shall allow gas to breathe from below to above the suspended deck, and vice versa, such that the differential pressure across the suspended deck does not exceed 2.4 mbar.

Direct gas streaming to the roof interspace shall be avoided.

Fittings that pass through the roof interspace and that could substantially cool the interspace gas shall be insulated.

The position of the deck shall be at a level not less than 0.5 m above the product design liquid level (see BS 7777-1).

COMMENTARY AND RECOMMENDATIONS ON 7.2.5.5. *A suspended deck has generally the form of a nominally flat surface attached by hangers to the outer roof. Its purpose is to support insulation and inhibit the flow of cold gas from the inner tank to the gas space between the inner and outer tank roofs. Since a suspended deck does not seal gas, the outer tank contains the gas pressure whilst the inner tank contains the hydrostatic pressure of the contained product. For tanks erected in areas of high earthquake incidence, consideration should be given to the suitability of suspended decks, owing to the effect of wave impact.*

The design should take into account the effects of thermal contractions that may arise in any part of the roof or shell under any possible operating conditions, as well as differential pressures that may occur across the suspended deck.

Depending on the lowest design temperatures, possible materials for suspended decks are as follows:

- carbon-manganese steel;
- aluminium alloy;
- 9 % nickel steel;
- stainless steel;
- timber.

Hanger attachments to the outer roof can be of material suitable for ambient temperature if the hanger locations can be shown to be at ambient temperature.

7.2.6 Inner tank nozzle and access openings

Inner tank nozzles and access openings shall be designed in accordance with 7.2.7.

Nozzles which pass through the outer tank and which contain a cold medium shall be thermally insulated from the tank structure to prevent local cold spots.

Loads from connecting piping shall be incorporated in the design of the shell or roof.

At least two manholes shall be installed for access to the inside of the tank.

NOTE Manholes should be in the roof, with a minimum diameter of 600 mm.

Where no access opening is possible in the outer tank, a manhole shall be installed in the inner steel tank to act as access opening into the inter-tank space during construction. An all-welded construction of double plate cover shall be used, so that the cover can be air pressure tested after the hydrostatic test at the end of the construction of the tank.

COMMENTARY AND RECOMMENDATIONS ON 6.2.6. *All pipe connections should preferably be made via the roof of the tank. This is based on the philosophy that the risk of serious leakage from the inner tank is thereby reduced to a minimum. In this way, the possibility of surroundings flooded by leaking product, with the risk of fire and explosion, is minimized.*

Where side or bottom entry is specified, the design should take account of the possibility of nozzle leakage, and its consequences, from the following causes:

- differential movement;
- thermal stress;
- stress intensification;
- pipe loads;
- difficulty of inspection/maintenance;
- foundation heating discontinuities;
- vulnerability of pipework to damage.

Local reinforcement at roof nozzles as a result of piping loads is permissible, particularly for tanks where the discharge is via submerged pumps.

For tank ancillaries, like level gauges, which are supported by the bottom of the tank, expansion facilities such as bellows are required at the roof penetrations to allow for differential movement between roof and pipe.

Platforms or ladders or stairways should be provided for access to roof nozzles which are equipped with instruments and valves.

During construction of the tank, a temporary opening may be made by leaving out a plate in the lowest course. This plate should be welded in at the end of the construction.

7.2.7 Design of inner tank mountings

7.2.7.1 General

The design of mountings attached to the inner tank shall take account of 7.1.6.

Where the inner tank has a fixed roof, the outlets shall be designed such that under normal operating conditions sufficient liquid remains in the tank to provide pressure on the floor plates to balance the interspace purge pressure.

COMMENTARY AND RECOMMENDATIONS ON 7.2.7.1. *Openings in the inner tank shell or roof normally provide for entry or exit of personnel, product or vapour to or from outside the outer tank to the inside of the inner tank. These openings pass through and form part of both tanks. 7.2.7 covers those parts that are directly attached to the inner tank. 7.1.6 covers those parts attached to the outer container and 7.2.8 covers the interconnections between inner and outer tanks.*

7.2.7.2 Shell openings

Connections to the inner shell shall be designed in accordance with 7.2.6.

Shell manholes and shell nozzles of outside diameter greater than or equal to 80 mm shall be designed in accordance with 7.1.6.2, except that the thickness of the manhole or nozzle body shall be not less than that given in Table 13.

Table 13 — Manhole and nozzle body thickness

Outside diameter d_n mm	Minimum manhole and nozzle body thickness t_p mm
$d_n \leq 50$	5.0
$50 < d_n \leq 70$	5.0
$70 < d_n \leq 100$	6.0
$100 < d_n \leq 200$	8.0
$200 < d_n \leq 300$	10.0
$300 < d_n$	12.5

Shell nozzles of outside diameter less than 80 mm shall require no additional reinforcement, provided that the thickness of the body is not less than that given in Table 13.

Shell nozzles shall be designed for the appropriate loads given in BS 7777-1:1993.

COMMENTARY AND RECOMMENDATIONS ON 7.2.7.2. *Connections to the inner tank should be avoided.*

Where possible, shell mounted nozzles should be shop-fabricated into shell plate.

Where used, shell mounted inlet and outlet connections should be provided with internal shut-off valves.

7.2.7.3 Roof openings

Pressure roof openings shall be designed in accordance with 7.1.6.4.

Safe access shall be provided through the suspended deck (see 7.2.5.5).

7.2.7.4 Bottom openings

Connections to the inner tank bottom shall be provided with shut-off valves for internal emergency shut-off conditions.

COMMENTARY AND RECOMMENDATIONS ON 7.2.7.4. *Connections to the inner tank bottom should be avoided.*

Bottom connections for totally emptying the tank prior to warm up and inspection are normally of small diameter. It is not advisable to operate the tank through the bottom connections, unless the design allows some liquid to remain in the tank.

Where openings are unavoidable, the following design procedure should be adopted.

- a) *Entry to the tank is as close to the shell as possible, but not less than 650 mm.*
- b) *The nozzle is positioned in an annular or sketch plate, enlarged if necessary for this purpose.*
- c) *The nozzle opening is reinforced on a replacement of area basis by a doubler plate, or thickened annular or sketch plate.*
- d) *The design should impose negligible bending moment on the inner tank bottom under all conditions of operation, particularly with reference to the differential contraction of the inner tank relative to the outer tank. (One way of doing this is to support the horizontal portion of the pipe from the underside of the inner tank shell/bottom junction by a strap welded to the underside of the annular plate and the top side of the pipe.)*
- e) *The pipe is always full of product in service.*
- f) *A high standard of construction and inspection is specified. (It is advised that the nozzle assembly is prefabricated into the thickened bottom plate and subject to inspection and testing prior to laying on the base insulation.)*
- g) *The unsupported area under the nozzle is kept to a minimum, and the surrounding insulation is designed for the higher load imposed on it. (It should also be capable of withstanding damage at the edges of the hole.)*
- h) *The space surrounding the nozzle and pipe is filled with suitable insulating material. (This is required elsewhere in this standard, for maintaining design metal temperature, local heat insulation characteristics, etc.)*

- i) *Anti-vortex provisions are considered.*
 j) *Additional localized base heating is considered.*

7.2.7.5 Nozzle welding details

Nozzle welding details shall be in accordance with 7.1.6.6. Set-on nozzles shall not be used (see Figure 18).

7.2.7.6 Inspection of mountings

The butt welds associated with fittings and insert plates shall be fully radiographed in accordance with 11.13.1.

All fillet welds and butt welds that cannot be examined by radiography shall be fully crack detected before the hydrostatic test (see 11.13.2).

COMMENTARY AND RECOMMENDATIONS ON 7.2.7.6. *The weld surface should be such that interpretation by crack detection or radiography is not impaired.*

7.2.7.7 Flanges

The flanges of all nozzles and manholes shall be made and drilled in accordance with class 150 of BS 1560-3.1:1989.

COMMENTARY AND RECOMMENDATIONS ON 7.2.7.7. *The design of the bolting system should take into account the low temperature conditions. Consideration should be given to differential contraction between bolt and flange, transient operating conditions and electrolytic corrosion (see 6.1.4).*

7.2.7.8 Permanent attachments other than manholes and nozzles

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 or vertical seam.

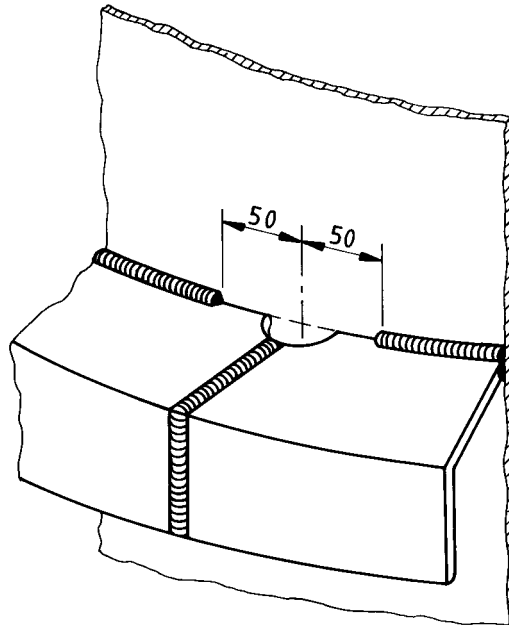
Permanent attachments shall be welded in accordance with 6.1.3. The soundness of fillet welds to the shell shall be checked by crack detection (see 11.13.2).

Radial joints in inner tank stiffeners shall be full penetration butt welds. Mouse holes shall be provided at the shell vertical weld seams and at the stiffener butt joints (see Figure 24).

7.2.7.9 Temporary attachments

Temporary attachments shall be cut off the shell plate 3 mm to 6 mm proud of the plate surface.

COMMENTARY AND RECOMMENDATIONS ON 7.2.7.9. *Temporary attachments may be knocked off the shell plate where the securing weld is weakened by chipping or gouging. Care should be taken not to damage the parent plate. The resultant scar should be ground to a smooth profile, minimizing local reduction in thickness of the plate. After grinding, the surface should be checked for cracks.*



Dimensions are in millimetres.

Figure 24 — Detail of stiffening ring radial joint (see 7.2.7.8)

7.2.8 Design of connections between the openings of the inner and outer tanks

7.2.8.1 General

Connections shall have a detailed design.

COMMENTARY AND RECOMMENDATIONS ON 7.2.8.1.

Particular attention should be paid to the design of details for the interconnecting mountings. This is to ensure that no maintenance or inspection is necessary during the operational life of the tank, since access to the interspace between the inner and outer tank is normally impossible.

Thermal and hydrostatic forces cause relative movement between the inner and outer tank, thus increasing or decreasing the interspace gap. Strain-absorbing connections are necessary to ensure that the relative movement does not induce unacceptable local stressing of the inner and/or outer tank.

7.2.8.2 Heat break

A heat break shall be fitted to connections between the inner and outer tank.

COMMENTARY AND RECOMMENDATIONS ON 7.2.8.2.

Heat breaks should be designed to prevent over-cooling of the outer shell.

7.2.8.3 Shell openings

Connections between openings in the inner and outer tank shells shall be designed to accommodate the differential movement between the shells (see Figure 25 and Figure 26).

Flanged joints shall not be located within the interspace between the inner and outer shells.

Where welded pipe is used, the welded seams shall be radiographed for the full length of the weld.

COMMENTARY AND RECOMMENDATIONS ON 7.2.8.3.

Connections should be made from seamless pipe.

7.2.8.4 Roof openings

Connections between openings in the inner and outer tank roofs shall be designed to accommodate the differential movement between the roofs.

For the suspended deck, connections shall be designed as an extension to the nozzle in the outer tank roof.

COMMENTARY AND RECOMMENDATIONS ON 7.2.8.4.

Movement between inner and outer tank roofs arises from either differential thermal expansion or contraction, or differing internal or external loads.

For suspended decks, the connection should be able to move freely through the suspended deck, thus eliminating additional loads on either the outer roof or the suspended deck (see 7.2.5.5).

7.2.8.5 Bottom openings

Where welded pipe is used, the welded seams shall be 100 % radiographed in accordance with 11.13.1.3.

COMMENTARY AND RECOMMENDATIONS ON 7.2.8.5.

Connections should be made from seamless pipe.

7.2.8.6 Materials

Materials selection for interconnecting pipework shall be in accordance with 6.1.

7.2.9 Tank anchorage design

7.2.9.1 General

Uplift of both inner and outer tanks or containers due to internal pressure shall be checked to determine if there is a possibility of the shell and adjacent bottom plating lifting off their seating under any condition of operating or testing. Where there is a possibility of uplift occurring, tank anchorages shall be provided.

COMMENTARY AND RECOMMENDATIONS ON 6.2.9.1.

Anchors should be capable of meeting seismic loading, where applicable, and wind loadings.

The designer of the tank foundation is responsible for the adequacy of the anchorage connection to the tank foundation.

Special attention should be given to the anchorage of the inner tank where it penetrates the outer tank bottom.

7.2.9.2 Design

The internal tanks and external tanks or containers shall be regarded as independent structures of which neither contributes to the other in resisting uplift.

A suspended deck shall be considered as an integral part of the outer tank.

Where insulation of the loose-fill type is used in the annular space between the inner tank shell and the outer tank shell or container, it shall not be regarded as providing resistance to uplift.

The inner tank anchorage shall take into account the following loads.

- a) *Service loads.* The uplift produced by roof design vapour pressure with seismic loads, counteracted by the effective weight of the shell, roof, roof structure, roof insulation and any permanently attached insulation.
- b) *Test loads.* The uplift produced by roof test vapour pressure counteracted by the effective weight of the shell and roof structure.

The outer tank or container anchorage shall take into account the following loads.

c) *Service loads.* The uplift produced by the annular space design pressure, with either:

- 1) wind uplift and overturning, or
- 2) seismic loads,

but not item 1) and item 2) simultaneously, counteracted by the effective weight of the shell, roof, roof structure, any associated structure attached to shell or roof, and/or any permanently attached insulation.

d) *Test loads.* The uplift produced by the annular space test pressure, plus 60 % of wind uplift and overturning, counteracted by the effective weight of the shell, roof, roof structure and any associated structure attached to the shell or roof.

Wind uplift pressure applied uniformly to the whole cross-sectional area of the tank or container shall be calculated in accordance with CP 3: Chapter V-2:1972.

Anchorage shall not be directly attached to shells or to bottom plates, but shall be attached to pads or brackets.

The design temperature for anchorage and anchorage attachments shall be either the design metal temperature of the tank or container, or a temperature agreed between the purchaser and the designer.

Under service conditions, the allowable stress for an anchorage shall not exceed 0.5 of yield strength for the material of construction.

The anchorage shall be capable of resisting the uplift produced by the test loads. For this condition the stress in the anchorage shall not exceed $0.85 \times$ the minimum yield strength of the anchorage material.

COMMENTARY AND RECOMMENDATIONS ON 7.2.9.2.
Both the inner tank and outer tank or container should be checked for combinations of loadings to establish the worst conditions of uplift. The anchorage and its attachment to the shell and foundation for each tank or container should be designed in accordance with the worst conditions of uplift.

Where the top shell course is thickened to provide additional compression area, the anchorage should be designed for $3 \times$ the design vapour pressure. The allowable stress for this loading may be increased to 90 % of the minimum specified yield strength of the anchorage material. The reason for this is that, with a thickened top shell course, the anchorage is underdesigned relative to the shell-to-roof connection. Designing the anchorage for $3 \times$ the design pressure ensures that the anchorage is in line with the roof-to-shell connection, in the event of an extreme overpressure. This recommendation should be regarded as a further increase in the safety of the

structure by ensuring that the weakest point of the structure is not at the bottom, but should not be regarded as a load condition for an undefined overpressure situation. The recommendation applies to all single containment tanks, the inner tanks of double containment tanks and the outer steel tanks of full containment tanks. The outer steel tanks of double containment tanks have an interspace open to the atmosphere which safeguards the outer shell or wall from overpressure.

Where the top shell course is thickened to provide additional compression area, but a normal anchorage is retained, the use of emergency pressure relief valves should be considered for single containment tanks, the inner tanks of double containment tanks and the outer steel tanks of full containment tanks.

Insulation firmly attached to the inner or outer tank may be regarded as resisting uplift on either tank. It is not normal to apply insulation until after the satisfactory testing of both tanks.

Anchorage design should allow for adjustment due to settlement prior to commissioning. All anchorages should be firmly embedded into the foundations. On no account should inner tank anchorages be embedded in the base insulation for the purpose of resisting uplift.

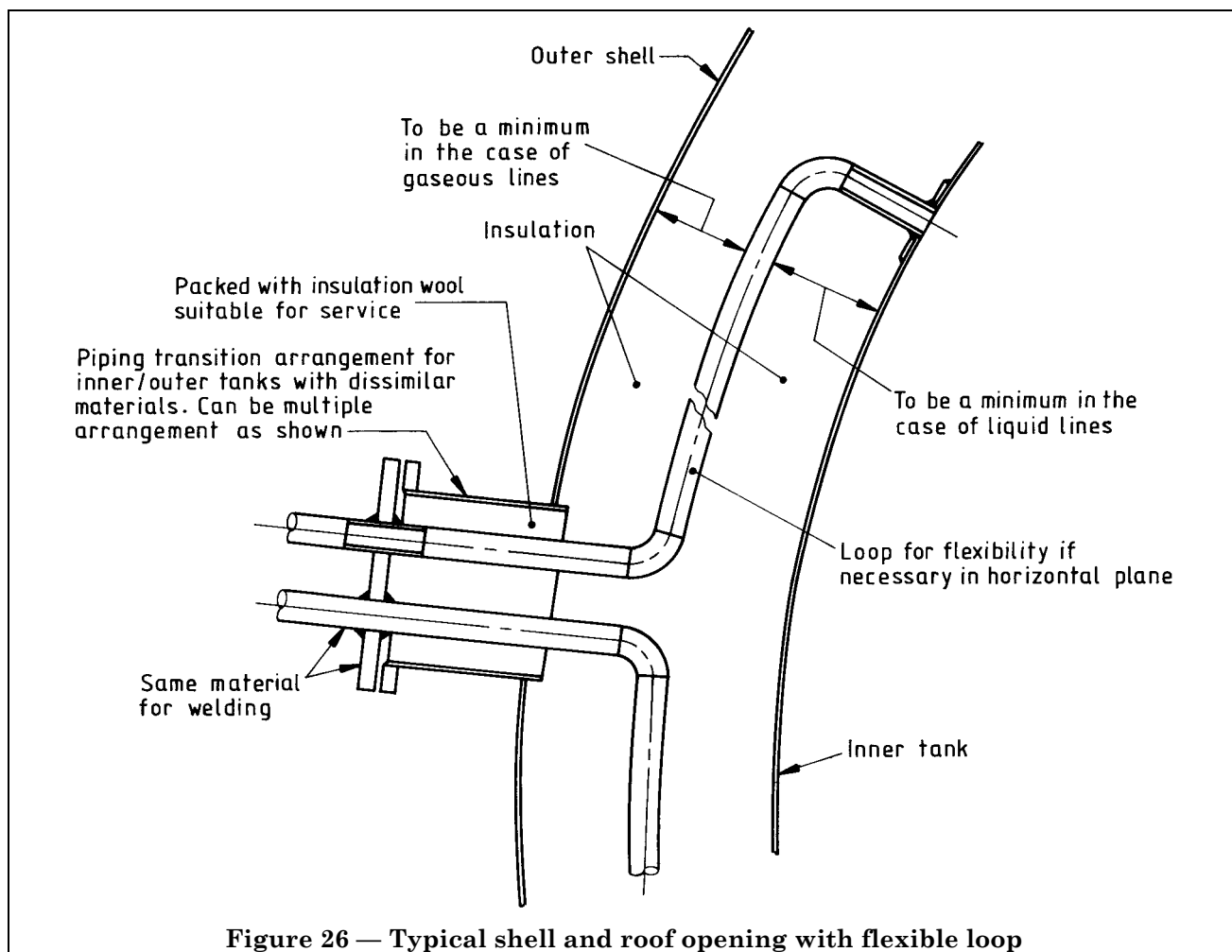
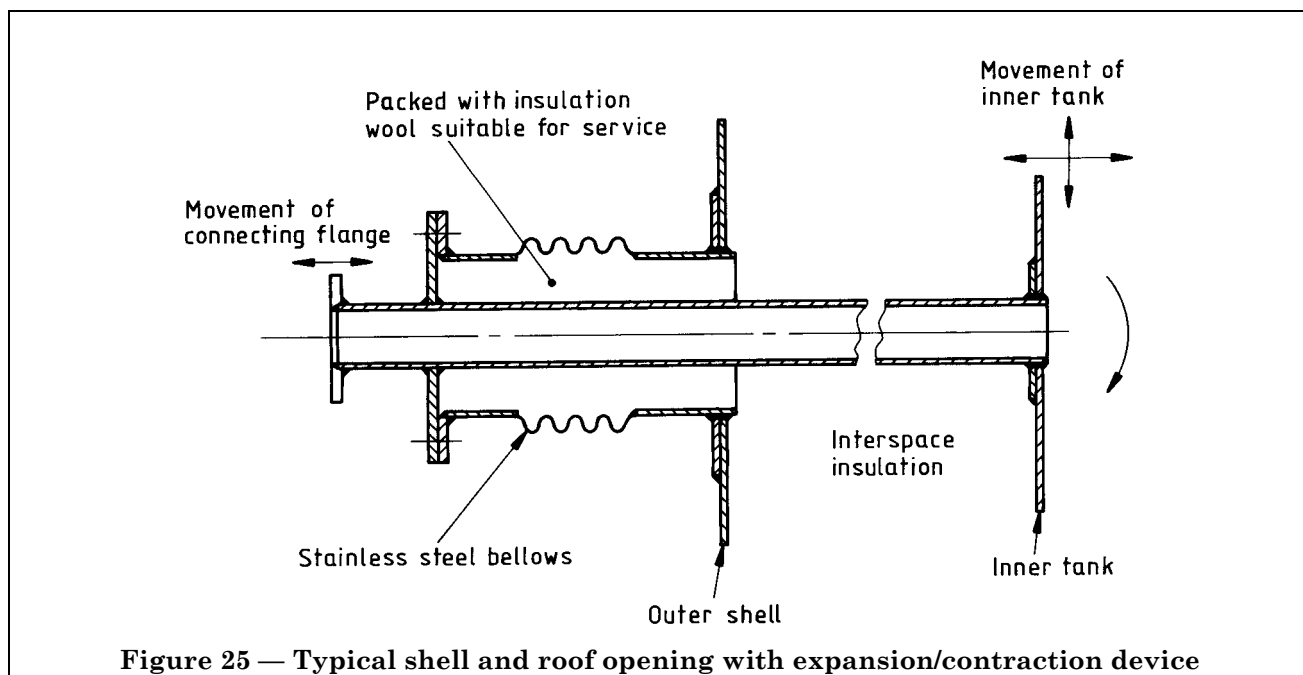
Tank design should accommodate movements due to temperature change to minimize induced bending stress in the shell. Any additional stress induced in the shell by the anchorage attachment to the shell should be checked to ensure that the allowable stress level of the shell is not exceeded for the condition of anchorage load considered.

Heat breaks may be required at the anchorage of inner tanks to prevent chilling of the outer tank and foundations. Heat transfer to the colder parts of the tank structure should be limited, to avoid failure of the anchorage or tank due to ice formation or water condensation.

A corrosion allowance of 1 mm should be applied to all surfaces of anchorage parts.

Any initial tension in the anchorage members, resulting from bolting loads or loads due to transient or long term thermal movement, should be considered in the anchor loadings.

No initial tension should be applied to the anchorage. It should become effective only when an uplift force develops in the shell of the tank or container. Steps should be taken before the tank goes into service to ensure that anchorage bolts cannot work loose or become ineffective over a long period.



7.2.9.3 Construction

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

COMMENTARY AND RECOMMENDATIONS ON 7.2.9.3.

Anchorage points should be spaced at a minimum of 1 m and at a maximum of 3 m and should, as far as possible, be spaced evenly around the circumference of the tank.

7.3 Steel single shell single containment tank for temperatures down to – 50 °C

NOTE For illustrations of a single shell single containment tank, see Figures 1a and 1b of BS 7777-1:1993.

7.3.1 Materials

All materials used in the manufacture of inner tanks to this standard shall be in accordance with clause 6.

7.3.2 Loadings

Tank loadings shall be in accordance with Table 1 of BS 7777-1:1993.

7.3.3 Bottom design

Bottom design shall be in accordance with 7.2.3.

7.3.4 Shell design

The shell design shall be in accordance with 7.2.4 and, in respect to wind and internal negative pressure design, shall be in accordance with 7.1.4.3.

7.3.5 Roof design

Roof design shall be in accordance with 7.1.5.

7.3.6 Tank anchorage

Anchorage shall be in accordance with 7.2.9.

7.3.7 Shell mountings

Mountings shall be in accordance with 7.2.6.

If pipe connections are made in the tank shell they shall be in accordance with 7.1.6.1 to 7.1.6.6.

COMMENTARY AND RECOMMENDATIONS ON 7.3.7. *All pipe connections should be through the roof of the tank (see 7.2.6).*

7.3.8 Roof mountings

Roof mountings shall be in accordance with 7.1.6.

8 Design of components for double containment tank

NOTE For illustrations of a double containment tank, see Figure 2 of BS 7777-1:1993.

8.1 Inner tank of double containment tank**8.1.1 General**

The inner tank shall be designed to store the product during service.

8.1.2 Tanks containing products at temperatures down to – 50 °C

The inner tank shall be designed in accordance with 7.3.

8.1.3 Tanks containing products at temperatures down to – 165 °C

The inner tank shall be designed in accordance with 7.2.

8.2 Steel outer tank of double containment tank

NOTE 1 For an illustration of an outer tank of a double containment tank, see Figure 2a of BS 7777-1:1993.

NOTE 2 Recommendations for outer tanks of prestressed concrete or reinforced concrete with an earth embankment are given in BS 7777-3. Requirements for steel outer tanks are given in 8.2.1 to 8.2.6.

8.2.1 General

The outer tank shall be designed to hold the liquid resulting from leakage of the product from the inner tank.

8.2.2 Design

The design of the outer tank with steel shell and bottom shall be in accordance with 8.1 and 8.2.4 to 8.2.6.

8.2.3 The maximum liquid filling height for outer tanks

The maximum liquid filling height for outer tanks shall be equal to the level reached when all the liquid from the inner tank is stored in both the inner and outer tanks, and results in equal levels in both.

8.2.4 Steel cover over the annular space

The steel cover shall be designed in accordance with BS 449-2:1969.

COMMENTARY AND RECOMMENDATIONS ON 8.2.4.

A steel cover may be installed over the annular space between the inner and outer tanks, to prevent rainwater entering.

8.2.5 Ventilation of the annular space

Where a steel cover is installed over the annular space, a ventilation opening shall be installed in the cover or in the top of the shell of the outer tank.

Wire netting frames shall be installed in ventilation openings to deny access to the interspace to nesting birds.

8.2.6 Design for wind loading

The shell of the outer tank shall be designed in accordance with 7.1.4.3.

Where no steel cover is installed over the annular space between the inner and outer tanks, or when it is not rigidly connected to the roof of the inner tank, then a top wind girder shall be installed on the steel outer tank in accordance with BS 2654:1989.

9 Design of components for full containment tank

NOTE For illustrations of components for a full containment tank, see Figure 3 of BS 7777-1:1993.

9.1 Inner tank of full containment tank

9.1.1 General

The inner tank shall be designed to store the product under normal operating conditions.

9.1.2 Design

For tanks containing the product at temperatures down to $-50\text{ }^{\circ}\text{C}$ or down to $-165\text{ }^{\circ}\text{C}$, the inner tank shall be designed in accordance with 7.2.

The design of the inner roof shall be in accordance with 7.2.5.

9.2 Steel outer tank of full containment tank

NOTE For an illustration of the outer tank of a full containment tank, see Figure 3a of BS 7777-1:1993.

9.2.1 General

The outer tank shall be designed to hold the liquid and vapour resulting from leakage of the product from the inner tank.

COMMENTARY AND RECOMMENDATIONS ON 9.2.1. *The outer tank may be constructed as follows:*

- a) *having a steel shell, bottom and roof (see Figure 3a of BS 7777-1:1993);*
- b) *having a prestressed concrete wall with a concrete floor and a concrete or steel roof (see Figure 3b of BS 7777-1:1993);*
- c) *having a reinforced concrete wall surrounded by an earth embankment, with a concrete floor and a concrete or steel roof (see Figure 3c of BS 7777-1:1993).*

9.2.2 Design

The design of the outer tank with steel shell and bottom shall be in accordance with 8.2.2, except as follows.

- a) The maximum filling height for an outer tank shall be in accordance with 8.2.3.
- b) The steel outer roof design shall be in accordance with 7.1.5.

10 Shop fabrication of tank components

10.1 Workmanship

The workmanship and finish shall be inspected by the manufacturer.

COMMENTARY AND RECOMMENDATIONS ON 10.1. *The purchaser may waive any part of his own inspection.*

10.2 Flattening

The mill tolerance shall be in accordance with the relevant plate material specification.

COMMENTARY AND RECOMMENDATIONS ON 10.2. *It may be necessary to specify closer tolerances in order to achieve the weld preparation tolerances required by the weld procedure. This will be dependent on the method of preparation specified.*

10.3 Hard stamping

For tanks designed for liquid containment, hard stamping of materials shall be permitted for plate identification only. In such cases, round-nosed stamps shall be used.

COMMENTARY AND RECOMMENDATIONS ON 10.3. *The hard stamping of materials should be controlled and limited.*

10.4 Plate edge preparation

The edges of plates shall be prepared by either machining, shearing, chipping, grinding, saw cutting or cutting with a machine-operated cutting torch.

For butt-welded joints, shearing shall be limited to 10 mm thickness of plates and shall be subject to agreement between purchaser and manufacturer. The sheared edge shall be cut back by either chipping, machining or grinding to smooth sound metal.

Plate laminations detrimental to welding shall be repaired or the plate replaced. All cut edges shall be visually examined.

Butt-welded plates shall be profiled to a tolerance of $\pm 2\text{ mm}$ for both length and width.

To ensure that plates are nominally rectangular, the diagonals, measured across the rectangle formed by scribing lines 50 mm from each edge, shall not differ by more than 3 mm.

COMMENTARY AND RECOMMENDATIONS ON 10.4. *Plate edge preparation should enable welding to be undertaken. In plate edge preparation, any incorrect profiling, edge imperfection, oxide, cutting scale, or burnt metal should be either machined, ground or chipped to sound metal before welding commences.*

If accuracy is not a major consideration, manual thermal cutting may be used for trimming the outside circumferential edges of roof or bottom sketch plates. Where thermal cutting followed by welding is to be carried out, radius arms, straight-edges and nozzle guides should be used wherever possible. The thermal cutting should leave sufficient metal for subsequent chipping, grinding or hand dressing to ensure welding is carried out on smooth sound metal to the profile requirements of the weld procedure.

10.5 Rolling and pressing

Shell plates shall be rolled to a prescribed curvature.

COMMENTARY AND RECOMMENDATIONS ON 10.5.

Preset of the ends of the shell plates is sometimes undertaken.

10.6 Shell nozzles and manholes

For shell nozzles and manholes, 7.1.6.7 applies.

10.7 Bolt holes

All bolt holes shall be drilled from a template so that similar parts are interchangeable.

Misaligned bolt holes shall not be corrected by drifting.

10.8 Shop painting

The method and extent of surface painting of tank materials shall be agreed between manufacturer and purchaser.

COMMENTARY AND RECOMMENDATIONS ON 10.8.

Consideration should be given to protecting welding margins, machined surfaces, nuts and bolts from corrosion during shipment and construction.

10.9 Erection marks

Erection marks shall be painted on plates and structural members in symbols not less than 50 mm high.

COMMENTARY AND RECOMMENDATIONS ON 10.9. *For tanks erected by the manufacturer, plates and structural members should be marked in accordance with the manufacturer's normal practice, or as specified by the purchaser.*

For tanks not erected by the manufacturer, to facilitate erection, plates and structural members should be marked in accordance with a marking diagram supplied by the manufacturer.

10.10 Packaging and identification

10.10.1 Structural materials and tank plates
All structural materials shall be suitably bundled and packaged.

COMMENTARY AND RECOMMENDATIONS ON 10.10.1.

Whenever possible, each case, bundle or package should be provided with suitable identification marks giving weight and other relevant details.

The handling facilities available in transit and the mode of transport should be taken into account when sizing the package to guard against damage or loss.

Flange gaskets should be packed separately for protection against damage in transit.

Roof and shell manholes, nozzles and bottom sumps on which covers are bolted, should be sent loose.

10.10.2 Welding electrodes

Welding electrodes shall be supplied in containers.

COMMENTARY AND RECOMMENDATIONS ON 10.10.2.

Welding electrodes should be given adequate protection against damage and moisture, in transit and during storage on site. The type of packing to be employed should previously have been specified by the electrode manufacturer.

10.11 Handling and transport

All materials shall be handled and transported as agreed between the purchaser and the erector.

COMMENTARY AND RECOMMENDATIONS ON 10.11.

9 % nickel steel is easily magnetized, and this can cause welding difficulties. Handling and transportation should be such that the plate, on arrival at site, has a residual magnetism that is not detrimental to welding operations.

A level of residual magnetism of 50 Gs is generally considered acceptable.

11 Site erection of tank components**11.1 General**

The erector shall supply all labour, false work, scaffolding, tools, welding machines, cables and electrodes for the erection of the tank.

COMMENTARY AND RECOMMENDATIONS ON 11.1.

Alternative or additional items of supply should be subject to agreement between the purchaser and the erector.

11.2 Workmanship

The workmanship and finish shall be inspected by the erector.

COMMENTARY AND RECOMMENDATIONS ON 11.2. *The purchaser may waive any part of his own inspection.*

11.3 Foundations

Foundations shall be in accordance with BS 7777-3:1993.

11.4 Rectification of materials damaged prior to erection

Any damage to materials shall be corrected to the satisfaction of the purchaser, prior to erection.

11.5 Erection of plates

A procedure shall be prepared prior to commencement of erection. The method proposed to hold the plates in position for welding shall be included in the procedure.

COMMENTARY AND RECOMMENDATIONS ON 11.5. *The first course of shell plates to be erected should be held in position by metal clamps or other devices, whilst it is plumbed and checked for circularity, and before it is tack welded or welded.*

Allowance should be made for the contraction of the vertical joints of the first shell course during welding.

All shell courses should be erected on a common centre line.

On all lap joints, the plates should be held in contact during the welding operation.

The surfaces where the weld metal is to be applied should be thoroughly cleaned before assembly.

Attachments welded to the inner tank and needed only for purposes of erection should be removed in accordance with 7.2.7.9.

11.6 Inner tank and outer tank or container erection tolerances

The foundation levels shall be checked by the erector before and during erection.

After welding the first erected course, the internal radial tolerance, when measured horizontally from the centre of the tank to any point on the inside of the tank shell, shall be as given in Table 14. The overall height of the shell shall not be out of vertical by more than 1 in 200.

Table 14 — Tank radius erection tolerances

Tank Diameter D m	Radial Tolerance mm
$D \leq 12.5$	± 13
$12.5 < D \leq 45$	± 19
$45 < D$	± 25

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) For completed vertical joints:
 - 1) for plates up to and including 19 mm thick, 1.5 mm or 10 % of plate thickness, whichever is the greater;
 - 2) for plates over 19 mm thick, 3 mm or 10 % of plate thickness, whichever is the greater.
- b) For completed horizontal joints:
 - 1) for plates up to and including 8 mm thick, 1.5 mm or 20 % of the upper plate thickness, whichever is the greater;
 - 2) for plates over 8 mm thick, 3 mm or 20 % of the upper plate thickness, whichever is the greater.

COMMENTARY AND RECOMMENDATIONS ON 11.6. *The overall vertical tolerance should apply to each individual course erected.*

Sharp changes in form should not be permitted. At horizontal and vertical joints the shell profile should not deviate from the theoretical versine, measured over a gauge length of 1 m, by more than is recommended in Table 15.

The inner and outer tank should be checked for circularity, dimension and level during the course of erection.

Table 15 — Tank shell profile tolerance

Tank plate thickness t mm	Profile tolerance mm
$t \leq 12.5$	10
$12.5 < t \leq 25$	8
$25 < t$	6

11.7 Manual cutting of plates

Manual cutting of plates shall be in accordance with 10.4.

11.8 Protection of shell during erection

The erector shall protect the shell from unacceptable damage during erection.

COMMENTARY AND RECOMMENDATIONS ON 11.8. *When required by the purchaser, full details of the methods used for protection should be made available for approval. The factors which should be taken into account when determining the suitability of the proposed method of protection are:*

- 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.

Consideration should be given to the use of temporary wind girders, since the use of steel wire guys or cables may not be adequate.

11.9 Erection of tank roof

Temporary support shall remain in position until the completion of the main and secondary framing.

COMMENTARY AND RECOMMENDATIONS ON 11.9. *When assembling roof plates on the framing, no excessive unsymmetrical loading should be applied to the roof members due to the stacking of roof plates.*

The strength of the temporary support should be calculated using the most unfavourable loading condition during erection.

When agreed between the purchaser and the erector, roofs may be erected on the tank bottom and raised into position by air pressure or other means.

11.10 Erection holes

Erection holes shall not be made in the plate work of shells and bottoms.

11.11 Welding**11.11.1 Welding procedure**

All welding, including repair, tack or attachment welding shall be carried out in accordance with the procedure established in **11.12.2** and by welders approved in accordance with **11.12.4**.

For the following materials, the indicated welding processes shall be used.

a) *Carbon steels*

Manual metal arc and multi-run submerged arc welding shall be used for all seams, except that CO₂ welding, using the spray transfer technique, is permitted for girth seams only.

b) *9 % nickel steel and stainless steel*

Manual metal arc, metal inert gas and tungsten inert gas welding shall be used for all seams, except that submerged arc welding is permitted for girth seams only.

COMMENTARY AND RECOMMENDATIONS ON 11.11.1.
When it is proposed to utilize welding processes other than those specified in this clause it may be necessary to modify or amplify the qualification tests to ensure a satisfactory result. Additional tests on welding procedures should be the subject of agreement between the purchaser and the erector.

11.11.2 Welding sequences

The production sequence for welded joints shall be the subject of agreement between the purchaser and the erector.

The sequence employed for tack welding and welding the bottom, shell or roof plates shall be such that the distortion due to welding shrinkage is minimized.

11.11.3 Weather conditions

When the parent metal temperature is lower than 0 °C, the surfaces on both sides of the joints shall be preheated to the temperature specified in the welding procedure and to a distance of not less than 4 × the plate thickness or 75 mm, whichever is the greater, in any direction before welding begins. During the course of the welding operation, this preheat temperature shall be maintained.

COMMENTARY AND RECOMMENDATIONS ON 11.11.3.
Welding should not be undertaken when the surfaces of the parts to be welded are wet, when rain or snow is falling on such surfaces, or when there are periods of high wind, unless the welder and the work are properly shielded.

11.11.4 Storage and handling of welding consumables**11.11.4.1 Consumables**

Consumables shall be stored and handled in accordance with the electrode manufacturer's recommendations. Electrodes, filler wires, rods and fluxes exhibiting damage or deterioration shall not be used.

COMMENTARY AND RECOMMENDATIONS ON 11.11.4.1.
Damaged or deteriorating electrodes, including those with cracked or flaked coatings, rusty or dirty electrode wires, and wires with flaked or damaged copper coatings, should not be used.

11.11.4.2 Covered electrodes

Covered electrodes shall be stored in their original containers in a dry heated place adequately protected from the effects of the weather.

Special conditions for protection or treatment during storage, or immediately prior to use shall be implemented.

Hydrogen-controlled covered electrodes shall be stored and baked.

Electrodes shall be removed from their original containers before drying or baking. After removal from the oven, the electrodes shall be protected from exposure to conditions conducive to moisture absorption.

Covered electrodes, when returned to stores, shall be conditioned like new electrodes before reissue.

COMMENTARY AND RECOMMENDATIONS ON 11.11.4.2. *If electrodes have been exposed to poor storage conditions, or it is suspected that they have become damp, the advice of the manufacturer should be sought before use.*

Where the lowest hydrogen levels are required, welders may be issued with electrodes in quivers or sealed containers.

11.11.4.3 Semi-automatic, automatic and mechanized welding

Wire or cored electrodes shall be packed to guard against damage, including that during transportation. When stored, the wire or electrode shall be kept in its original bundle or package in a dry storeroom.

Flux shall be packed such that it is protected from moisture pick-up and damage during storage and transportation. Flux with a guaranteed moisture level, or giving a controlled hydrogen level as deposited, shall be packed in moisture-resistant containers. When stored, the flux shall remain in its original container in a dry storeroom.

If the composition of the flux is such that special protection during storage or special treatment before use is necessary, details of such special protection or treatment shall be provided by the electrode manufacturer, and implemented by the erector.

COMMENTARY AND RECOMMENDATIONS ON 11.11.4.3.

The performance of copper coated wires depends on the continuity and regularity of the copper coating, which is often not apparent on visual inspection but could be important in critical applications. This consideration should be agreed between the erector and the supplier of the copper coating wires.

For unused flux, moisture pick-up, particle break-down or alloy balance should be assessed.

Unfused recovered flux can be reused where its properties are acceptable.

11.11.5 Tack welds

For tanks designed for liquid containment, tack welds used in the assembly of the vertical joints of tank shells and manually welded horizontal joints of tank shells shall be removed from the finished joint.

COMMENTARY AND RECOMMENDATIONS ON 11.11.5.

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 passes are thoroughly fused into the tack welds.

For tanks not designed for liquid containment, tack welds by qualified welders need not be removed provided they are sound and the subsequent weld passes are thoroughly fused into the tack welds.

11.11.6 Visual inspection

All welds shall be visually inspected in accordance with BS 5289:1976.

11.11.7 Cleaning of welds

Each run of weld metal shall have slag and other deposits removed before the next pass is applied.

Slag shall be removed from the finished weld before inspection.

Where air-arc gouging is used, the surfaces shall be chipped or ground back to bright metal before welding.

11.11.8 Back gouging and chipping

The reverse side of a full-penetration butt weld shall be cleaned prior to the application of the first bead to this side.

COMMENTARY AND RECOMMENDATIONS ON 11.11.8.

The exposed surface should be suitable for proper interfusion with the deposited weld metal. This may be done by chipping, grinding or gouging, or, where the back of the initial bead is smooth and free from crevices that might entrap slag, no preparation is required.

11.11.9 Weld reinforcement

The weld metal on each side of a butt joint shall be built up so that the finished face in the area of fusion extends above the line between the edges of adjoining plates.

11.11.10 Undercutting

Undercutting of the base metal shall not be greater than 0.5 mm in depth. On horizontal butt joints and fillet welds, undercut shall not exceed 1 mm in depth.

COMMENTARY AND RECOMMENDATIONS ON 11.11.10.

The edges of welds should merge smoothly with the surface of the parent plate and sharp angles should be avoided.

11.11.11 Peening

Peening of welds shall not be permitted.

11.11.12 Repairs

Unacceptable defects in welds shall be brought to the attention of the purchaser's inspector.

Approved methods of repair shall be utilized.

For a tank designed to contain liquid, a repair shall be carried out where welded joints do not conform to 11.13.1.4. The repair shall be 100 % radiographed.

For a tank not designed to contain liquid, where a section of weld, shown by radiography, is unacceptable, and the limit of the defective welding is not defined by such radiography, two adjacent spots shall be examined by radiography. If the weld at either of these sections fails to conform to 11.13.1.4, two additional spots shall be examined until the limits of such welding are determined.

All defects outside the scope of 11.13.1.4 shall be removed by chipping, grinding or gouging from one or both sides of the joint, and rewelded.

11.12 Welding procedure approval and welder approval

11.12.1 General

Welding processes used for the construction of a tank or container shall be in accordance with the welding procedure approval test and welder approval test (see 11.12.3 and 11.12.4).

Welding procedures for liquid containing tanks shall be approved in accordance with 11.12.3 and all welders shall be approved in accordance with 11.12.4.

Welding procedures for non-liquid containing outer containers (see 7.1) shall be approved in accordance with BS EN 288-3:1992.

Previously approved procedures and previously approved welders shall be accepted as agreed between purchaser and manufacturer and/or erector.

Consumables used for weld procedure approval and welder approval shall be the same as those to be used for construction.

11.12.2 Welding procedure approval

The welding procedure specification shall include details of the welding process and the welding procedure to be used by the erector, including details of repair, tack and attachment welds. The results of approval testing of the welding procedure shall be included on the test certificate.

COMMENTARY AND RECOMMENDATIONS ON 11.12.2. *No procedure test is necessary for welding a lap welded suspended deck, where the pressure is balanced across it.*

Where service conditions require limits on hardness, the weld procedure qualification should be agreed between the purchaser and the erector.

11.12.3 Approval tests of welding procedure

11.12.3.1 General

The number and type of test plates shall be selected from item a), item b) or item c), as appropriate:

- a) one butt welded in the horizontal position and one butt welded in the vertical position, of thicknesses equal to the minimum shell plate thickness $\pm 25\%$ and the maximum full tensile stressed shell plate thickness $\pm 25\%$;
- b) in accordance with BS EN 288-3:1992;
- c) in accordance with this standard.

Welding procedure tests for nozzle repair, tack and attachment welds shall not be required, provided that the process and consumables have been approved on a weld test plate in accordance with BS EN 288-3:1992.

Welding procedure tests for lap or butt welded bottom plates shall not be required, provided that the welding consumables have been qualified in accordance with 11.12.1.

Where a weld joint factor of 0.35 for single fillet weld, or 0.65 for a double fillet weld, is exceeded for a particular application, or the roof is wholly or partially butt welded, welding procedure tests shall be required.

11.12.3.2 Test plates

Butt welded test plates shall be prepared, radiographed and assessed in accordance with BS EN 288-3:1992. Destructive testing shall be in accordance with BS EN 288-3:1992, except that two transverse tensile specimens shall be tested.

Transverse tensile test specimens shall be full plate thickness. The transverse test strength shall be not less than the value used in design (see 7.2.4.1) for vertical welds, or 80 % of that value for horizontal welds. If fracture occurs in the weld metal or the heat affected zone, the weld metal proof stress or yield stress shall be determined in accordance with item a) or item b), as follows.

- a) Strain-gauged transverse tensile testing shall be in accordance with Annex B. The weld metal proof stress and tensile stress shall be not less than the value used in design (see 7.2.4.1) for vertical welds, or 80 % of that value for horizontal welds.
- b) For the longitudinal all-weld metal tensile test, the cross-sectional area of the reduced section of the test specimen shall be etched to demonstrate that it is all weld metal. The weld metal proof stress and tensile stress shall be not less than the value used in design (see 7.2.4.1) for vertical welds, or 80 % of that value for horizontal welds.

Charpy V-notch impact test specimens shall be selected, machined and tested in accordance with Figure 27 and with BS EN 10045-1:1990. Weld metal impact values shall be in accordance with 6.1.3.

COMMENTARY AND RECOMMENDATIONS ON 11.12.3.2. *If a strain gauged tensile test is used, the initial transverse tensile specimens need not be tested.*

11.12.3.3 Retesting

Where tests fail to meet the specified requirements, for each test piece that fails, retests shall be permitted as follows.

- a) If a tensile test result is unacceptable, but is not less than 95 % of the minimum specified value, two retests shall be made and both shall be in accordance with specified requirements. Where the tensile test result is less than 95 % of the minimum specified value, a new procedure shall be tested.
- b) If one Charpy V-notch specimen fails, three further specimens shall be prepared and tested. If any of the retests fail, the procedure shall be not accepted and a new procedure shall be tested.

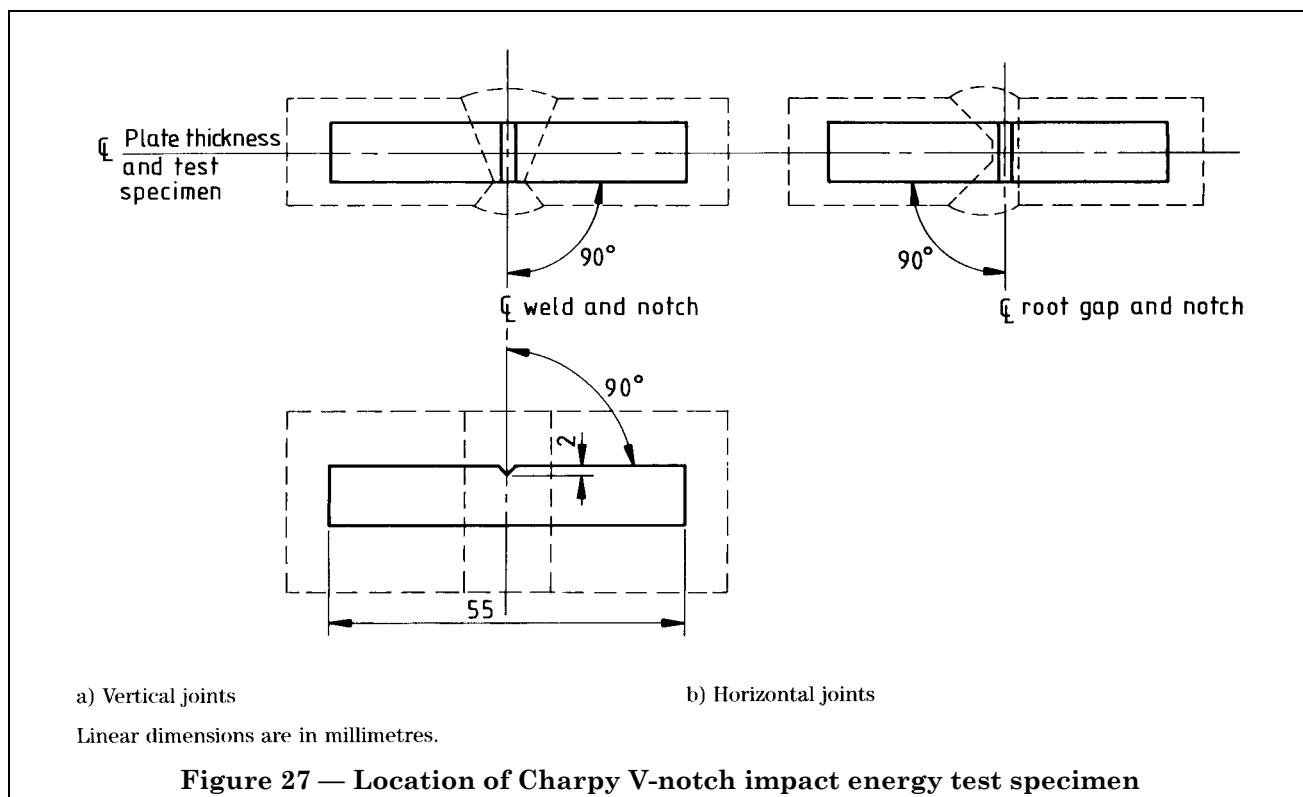


Figure 27 — Location of Charpy V-notch impact energy test specimen

11.12.3.4 Changes to welding procedure

A welding procedure test shall be required when any of the changes specified in BS EN 288-3:1992 and/or the following changes are made to an approved welding procedure:

- for the welding consumable, a change of brand;
- for the welding procedure, an increase or decrease in the diameter of the electrode;
- for a specified weld preparation in plates 12.5 mm thick and thicker, a change of more than $\pm 25\%$ in the number of runs. If the cross-sectional area of the groove is increased, the number of runs shall be increased in proportion to the area;
- for automatic girthseam welding, a change from multiple runs per side to a single run per side;
- for automatic girthseam welding, a change from single arc to multiple arc or vice versa.

11.12.4 Welder approval

Welders shall be approved before undertaking welding on the tank. A welder who has successfully completed a welding procedure test plate shall be considered to be approved.

Each welder shall be approved in accordance with BS EN 287-1:1992 and this Part of BS 7777.

Each butt welded test plate shall be radiographed and assessed in accordance with BS EN 287-1:1992.

COMMENTARY AND RECOMMENDATIONS ON 11.12.4. *Welder approval is not necessary for tack welding the shell, roof or bottom, where the tack weld can be removed by gouging or can be completely fused. Non-approved operators for such welding should be instructed and supervised.*

11.12.5 Welding records

Copies of welder approval records shall be available for examination on site by the purchaser.

A welder approved in accordance with 11.12.4 shall not be prevented from undertaking production work, pending examination of the welding records, or certified copies.

11.13 Non-destructive testing

11.13.1 Radiography

11.13.1.1 Surface preparation

Surface irregularities that confuse or mask any objectionable defect shall be removed.

COMMENTARY AND RECOMMENDATIONS ON 11.13.1.1. *The rigorous removal of surface irregularities, particularly those in 100% radiographed horizontal seams, should be avoided.*

11.13.1.2 Extent of radiography

For butt welds, the extent of radiography shall be as follows.

a) *Tank shells not designed to contain liquid*

For each welder, there shall be one radiograph for the first 2 m of a completed vertical joint welded.

Without regard to the number of welders, the following incidence of radiography shall be maintained:

- 1) 1 % of vertical seam length for each plate thickness;
- 2) 1 % of horizontal seam length for each plate thickness.

A change of ± 1 mm shall be considered as the same thickness.

b) *Tank shells designed to contain liquid*

Vertical and horizontal shell seams, butt welded joints in shell stiffeners and butt welded joints in shell and roof compression areas shall be 100 % radiographed.

All butt welds in bottom annular plates, insert plates and fittings shall be 100 % radiographed.

Butt welds in liquid containing pipework between tanks shall be 100 % radiographed.

No radiographic inspection shall be required for shell to annular welds or for butt welds used in the roof or bottom.

11.13.1.3 Radiography procedure

Radiography procedure shall be as follows.

- a) For tanks designed to contain liquid, radiography shall be carried out in accordance with BS 2600-1:1983, using techniques 1 or 2. For tanks not designed to contain liquid, gamma-radiography shall be in accordance with BS 2600-1:1983, using techniques 3, 6 or 7 and iridium 192.
- b) Lead intensifying screens shall be used and their thicknesses shall be in accordance with Table 3 of BS 2600-1:1983.
- c) Radiographic 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 an image quality indicator.
- d) Exposing, processing and handling procedures for film shall be demonstrated and subject to the approval of the purchaser. A standard test radiograph shall be prepared and shall be made available for inspection.

e) An image quality indicator in accordance with BS 3971:1980 shall be used, with dimensions appropriate to the thickness of the weld. The method of assessing the radiographic sensitivity shall be in accordance with BS 3971:1980.

f) Film shall be located adjacent to the weld surface during exposure.

g) An identification marker, the image of which appears on the film, shall be placed adjacent to the weld at each spot examined and its location accurately marked near the weld on the outside surface, so that a defect appearing on the radiograph shall be accurately located.

h) A reference marker shall be visible on each film.

i) Radiographs shall be submitted to the purchaser's inspector.

COMMENTARY AND RECOMMENDATIONS ON 11.13.1.3.

Care should be taken to ensure that films are carefully handled and stored. They should not be subject to mechanical or chemical damage and it is important to guard against inadvertent exposure to actinic light, radiation or excessive heat.

11.13.1.4 Radiographic acceptance

Radiographic acceptance shall be as follows.

- a) Sections of weld shall be sentenced as unacceptable if shown by radiography to have any of the following imperfections.
 - 1) Cracks or lack of fusion.
 - 2) Incomplete penetration except as permitted in 7.1.4.5 and 7.2.4.7.
 - 3) Individual elongated inclusions having a length greater than two-thirds of the thickness of the thinner plate of the joint. Regardless of the plate thickness, no inclusion shall be longer than 19 mm nor shall inclusions shorter than 6 mm be considered non-compliant.
 - 4) Any group of inclusions in line, where the sum of the longest dimensions of all such imperfections is greater than t , where t is the thickness of the thinner plate joined, in a length $6t$. Where the individual spaces between imperfections is greater than $3 \times$ the length of the longest of the adjacent imperfections, the imperfections shall be judged as individual or groups.
- b) Inspection of repaired welds (see 11.11.12).
- c) Record of radiographic examination shall be as follows.
 - 1) The erection contractor shall make a record of all films, with their identification marks, on a developed shell plate diagram.

- 2) After completion of the tank, the films shall be retained for a minimum period of 5 years.

COMMENTARY AND RECOMMENDATIONS ON 11.13.1.4.

Scattered porosity is not detrimental to the mechanical properties of welded joints. It is better to limit repairs to a minimum, rather than to cut out minor local porosity, unless it is consistently in excess of 2 % by area (as seen in a radiograph). The area considered should be the length of the weld affected by porosity multiplied by the maximum width of the weld locally.

11.13.2 Surface crack detection

Tank anchorage to shell welds shall be crack detected before and after the hydro-pneumatic test. The compression ring to shell welds shall be crack detected inside and outside.

Nozzle welds in liquid containing tanks shall be crack detected inside and outside.

Stiffener welds on liquid containing tanks shall be 100 % crack detected.

The bottom to shell joints of liquid containing tanks shall be 100 % crack detected.

Crack detection shall be performed in accordance with BS 6072:1981 or with BS 6443:1984.

11.13.3 Leak testing

11.13.3.1 Extent of vacuum box examination

Extent of examination by vacuum box shall be as follows.

- a) Bottom seams of outer tanks, not designed to contain liquid, shall be examined for leakage for 100 % of their length prior to the construction of tanks designed to contain liquid.
- b) Bottom seams of tanks designed to contain liquid and single containment tanks shall be examined for leakage for 100 % of their length before hydrostatic testing. After hydrostatic testing, examination shall be carried out on single containment tank bottoms and inner tank bottoms of double and full containment tanks.
- c) More extensive vacuum box examination than specified in items a) and items b) shall be by agreement between the purchaser and the contractor.

11.13.3.2 Vacuum box procedure

Bottom seams shall be tested using a pressure of 650 mbar absolute (i.e. 350 mbar of vacuum).

11.13.3.3 Testing of shell-to-bottom junction

Testing of the shell-to-bottom junction shall be as follows.

- a) For tanks not designed to contain liquid, this junction shall be tested by a specially constructed vacuum box and in accordance with 11.13.3.2.

- b) For tanks designed to contain liquid, with a double fillet welded shell-to-bottom joint, the weld shall be tested for leakage inside and outside, by pressurizing the volume between the welds with air [3 to 7 bar (gauge)] and applying a soap film or other suitable material to both welds.

- c) For tanks designed to contain liquid, with full penetration welds between shell and bottom joints, the welds shall be 100 % magnetic particle inspection (MPI) or dye penetrant inspection (DPI), internally and externally, and vacuum box tested internally.

COMMENTARY AND RECOMMENDATIONS ON 11.13.3.3.

For tanks designed to contain liquid, where the double fillet shell-to-bottom weld is tested for leakage, to ensure that air pressure reaches all parts of the weld, a sealed blockage in the annular passage between the inside and outside weld should be provided by welding at one point only. A small pipe coupling welded to the outside fillet weld, communicating with the space between the welds, should be welded on each side of and adjacent to the blockage. The air supply should be connected to one of the couplings and a pressure gauge to the other. Couplings should be removed after satisfactory testing and the weld made good.

12 Pressure testing of both inner and outer tank

12.1 Hydrostatic testing

12.1.1 Inner tank testing

The inner tank shall be filled with the test liquid to the maximum design product level (see 7.2.4.3).

All joints shall be examined for leakage. The vacuum box test on the bottom plate welds (see 11.13.3) shall be repeated after the hydrostatic test to detect for small leaks.

COMMENTARY AND RECOMMENDATIONS ON 12.1.1. *Full height hydrostatic testing ensures that the tanks and their foundations are satisfactorily designed and constructed, the tanks are liquid tight and peak stresses in the steel introduced during fabrication are reduced at ambient temperature.*

12.1.2 Testing of outer steel tanks for double and full containment

The outer tank shall be filled to such a height that it contains the test liquid of a full inner tank.

COMMENTARY AND RECOMMENDATIONS ON 12.1.2.

When the outer steel tank is tested, care should be taken during emptying to prevent damage to the inner tank. The liquid level in the annular space should be equal to or less than that of the inner tank, to prevent compressive stresses in the inner tank or bottom uplift.

The bottom insulation of the inner tank should be adequately protected against the danger of liquid penetration during testing.

12.1.3 Test procedure

The test procedure shall be agreed between the purchaser and the erector.

COMMENTARY AND RECOMMENDATIONS ON 12.1.3. *The test procedure assumes that water at ambient temperature is available as a test fluid for the inner tank.*

The rules given in the test procedure are formulated to give stresses appropriate to the design conditions and the materials of construction.

The limits for differential and uniform settlement should be specified, and a comprehensive test procedure should be agreed. Water filling should be stopped immediately if the settlement exceeds that specified.

Attention should be paid to the control and monitoring of pressures during all stages of testing, including the checking of internal positive pressure and vacuum relief vents.

Climatic changes cause sharp fluctuations in test pressure. Provision should be made for the safe relief of internal positive pressure or internal negative pressure in the event of such fluctuations, or if the relief vents fail to operate at the design pressures whilst under test.

The hydrostatic test should be completed before the application of the shell and external roof insulation.

The suitability of the water for hydrostatic testing should be considered, taking account of the time the tank is exposed to it. Attention should be paid to the chloride content, and in the case of 9 % nickel steel tanks, to the hydrogen sulphide content.

The tank should be freely vented to atmosphere during filling and emptying.

During filling, and when filled to the test level, the tank and foundations should be inspected for leakage, mechanical damage and foundation settlement.

To counter possible compaction of the bottom insulation, the anchorage, if provided, should be checked and retightened, after filling with water but before applying, the air test.

During the water filling, all welded joints should be visually examined for leakage.

12.2 Pneumatic testing

12.2.1 Testing of inner tanks with integral roofs

For a tank filled with water to the test water level, and after completion of all requirements of 12.1.3, the enclosed space above the water level shall be pressurized with air equal to $1.25 \times$ the pressure for which the vapour space is designed.

The test procedure shall be agreed between the purchaser and the erector.

COMMENTARY AND RECOMMENDATIONS ON 12.2.1. *A typical pneumatic test procedure is as follows.*

- a) Adjust the pressure relief vents to enable the enclosed space to be pressurized in accordance with 12.2.1. Increase the pressure to this value and hold for 15 min.*
- b) Reduce the air pressure to the vapour space design pressure. Check all welded joints above the water level by applying soap film or other suitable material to the welded joints. This should include all shell joints, all welded joints in the roof, around openings and in all piping against which the pneumatic pressure is acting.*
- c) Readjust the pressure relief vent setting so that the normal opening pressure can be checked by pumping air into the space above the water level. Check the opening pressure for the vacuum vent by partial withdrawal of water from the tank.*
- d) Vent the tank to atmosphere and empty the tank of all test water.*
- e) Recheck and retighten the anchorage (if provided) after the tank has been emptied of water and is at atmospheric pressure.*
- f) Apply air pressure, equal to the design pressure, to the empty tank and check the anchorage and foundation for uplift.*

12.2.2 Testing of outer tanks and containers

With a pneumatic pressure, in accordance with 12.2.1, acting against the outer tank or container, the testing requirements shall result in a test of the outer tank or container.

The test procedure shall be agreed between the purchaser and the erector.

COMMENTARY AND RECOMMENDATIONS ON 12.2.2. *This agreed test procedure is intended for that part of the outer tank or container that has not been pressurized during the testing of the inner tank. It is recommended that the inner tank is filled with water to reduce air volume during the test.*

A typical pneumatic test procedure is as follows:

a) *Either vent the inner tank to atmosphere and pump in sufficient water to balance the upward pressure against the inner tank bottom that is produced by the pneumatic test of the outer tank or container; or, as an alternative, equalize the pressure between inner and outer tanks, but consider the possibility of pressure differentials across the inner tank bottom when testing the vacuum relief vent setting.*

b) *Apply air pressure to the space enclosed by the outer tank or container equal to at least the design gas pressure, but not exceeding a pressure that would overstress either the inner tank or the outer tank or container.*

c) *Test all welded joints by applying soap film, or other suitable material, at the air pressure specified.*

d) *Adjust the air pressure to the design gas pressure for the outer tank or container and check the pressure relief valve. Evacuate the air enough to check the vacuum relief valve.*

e) *Vent both outer space and inner tank to atmosphere and withdraw any water from the inner tank.*

There is the intent that the outer tank or container should be leaktight before the commencement of commissioning. Mechanical joints should therefore be tested for leaktightness during the testing of the tank, but any joints subsequently broken and remade should be inspected and possibly retested prior to cooldown.

13 Insulation

Insulation shall be in accordance with **6.6**, clause **10** and clause **14** of BS 7777-3:1993.

14 Foundations

Foundations shall be in accordance with clause **7** of BS 7777-3:1993.

15 Internal positive and internal negative pressure relief

Internal positive and internal negative pressure relief shall be in accordance with clause **8** of BS 7777-1:1993.

When additional relief capacity is fitted to the inner tank, the additional devices shall, under normal operating conditions, be available for operation.

16 Commissioning and decommissioning

Commissioning and decommissioning shall be in accordance with clause **9** of BS 7777-1:1993.

17 Name plate

A name plate shall be permanently fixed at a place agreed between the purchaser and the contractor and shall give the following information when applicable:

- a) the name of the contractor;
- b) the stored liquid;
- c) the tank capacity;
- d) the construction, i.e. single, double or full containment;
- e) the inner tank design pressure, positive and negative;
- f) the inner tank design temperature, maximum and minimum;
- g) the outer tank or container design pressure, positive and negative;
- h) the outer tank or container design temperature, maximum and minimum;
- i) the year of construction;
- j) the number and date of this British Standard, i.e. BS 7777-2:1993.

Annex A (informative)**Guidance for the determination of ΔT -shift for the impact testing of steels****A.1 Introduction**

This annex gives the test method to be used by the steelmaker to determine ΔT .

There is not a requirement to determine ΔT for a weld procedure test (see **11.12.3**). Guidance has therefore been included as an annex since it is recognized that Charpy V (C_v) testing is the most widely used standardized method for materials toughness testing, despite its limitations.

The desired impact value for any plate in the tank measured in the heat affected zone (HAZ) is 27 J at the design temperature for double and full containment tanks, and 27 J at $25\text{ }^\circ\text{C} \pm 5\text{ }^\circ\text{C}$ lower than the design temperature for single containment tanks.

To ensure that the material does not have a flat energy versus temperature relationship, the material should demonstrate that the C_v transition temperature is within $30\text{ }^\circ\text{C}$ of the test temperature. To this end, a higher energy value of 120 J gives a reasonable demonstration.

To achieve the necessary value of 27 J for any tank plate, with a degree of assurance, the steel should be tested to demonstrate the shift in temperature at the 27 J C_v level for the HAZ, compared with the plate material. This shift is defined as ΔT .

The determination of ΔT for a specific steel is required to be repeated when a steelmaking process route is amended, since minor micro-alloy elements, desulfurization, deoxidation, casting and other steelmaking practices can affect the response of the steel to welding.

After determining ΔT , each plate should then be tested at a temperature ΔT below the design temperature, hence ensuring that the 27 J will still be achieved in the degraded HAZ, and tested on a batch basis at the higher temperature to demonstrate the 120 J requirement.

A.2 Frequency of testing

Where it is necessary to determine ΔT , the tests should be carried out on the steel, and should be repeated if any changes are made to the following:

- a) steelmaker;
- b) steelmaking process;
- c) deoxidation practice;
- d) desulfurization practice;
- e) casting practice;
- f) heat treatment;
- g) change in specified chemical composition including micro-alloy additions.

A.3 Test plate

The test plate should be in accordance with Figure A.1, and should be welded in the flat position using manual metal arc welding.

The welding should be carried out in accordance with Table A.1, and with Figure A.2.

The purchaser and the manufacturer or the erector should agree which electrode should be used for the test.

Table A.1 — Test plate welding characteristics

Electrode diameter mm	Typical current A	Typical run-out length/electrode mm	Necessary heat input kJ/mm
5	270	140	3.5 to 4

A.4 Testing

On completion of welding, Charpy impact specimens should be removed in accordance with Figure A.3. The HAZ and plate Charpy specimens should be tested at suitable temperatures to determine the transition curves for the two sets of specimens. Particular attention should be paid to testing at temperatures where 27 J is obtained.

From the two curves, ΔT is determined. This is the shift in temperature of the 27 J transition temperature (see Figure A.4).

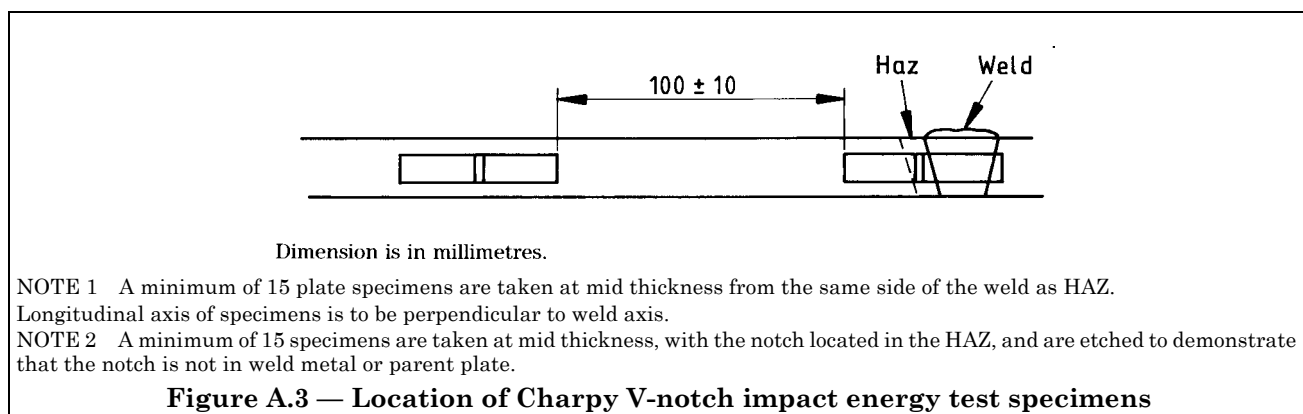
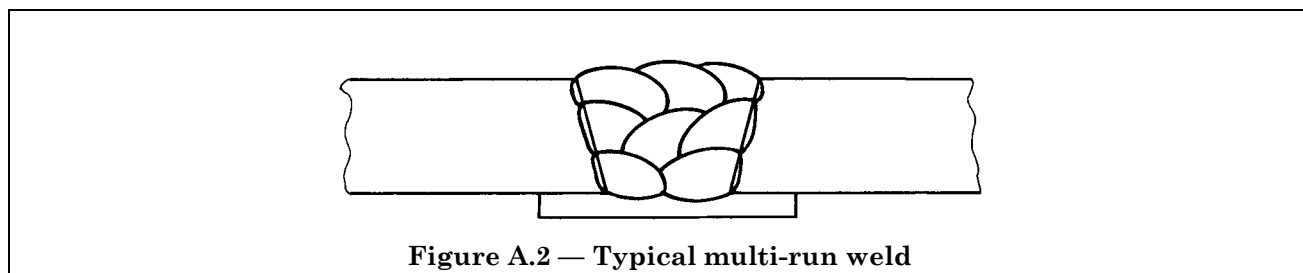
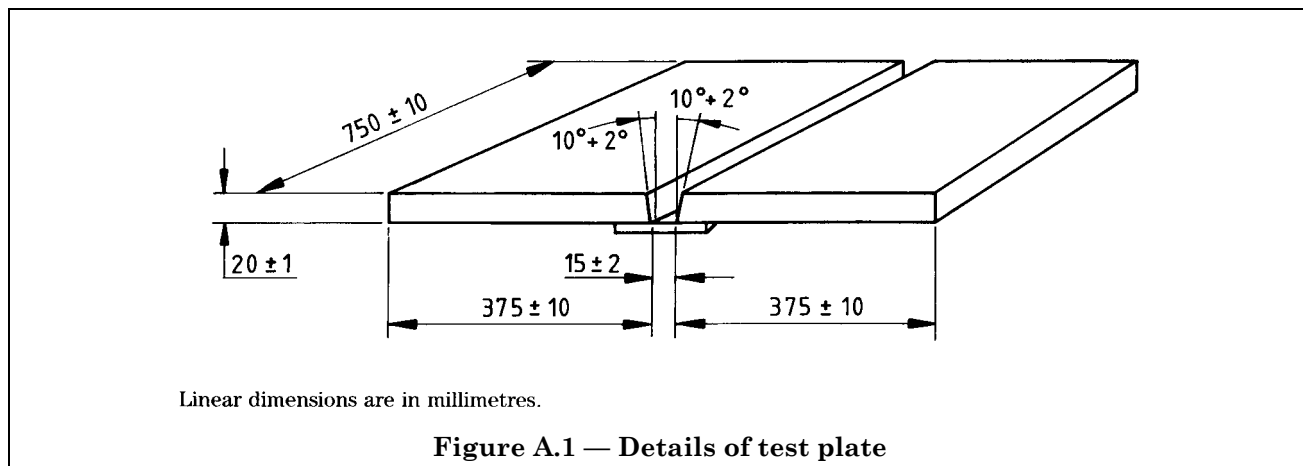
Where a transition temperature at 27 J cannot be determined, because of a high energy level bottom shelf, then a 45 J level should be used, or a value agreed between the purchaser and the manufacturer or erector.

A.5 Verification

The testing should be witnessed and verified by an independent inspection authority and full documentation should be supplied by the tester on request.

Test plates should be unrestrained.

Test plates should be welded complete with a maximum time of 1 h between runs.



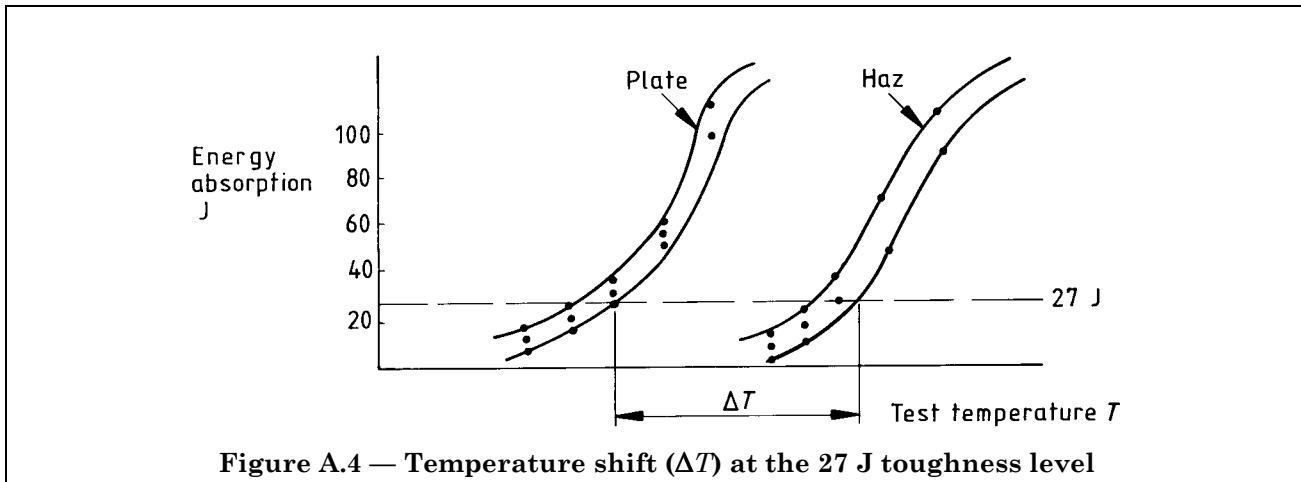


Figure A.4 — Temperature shift (ΔT) at the 27 J toughness level

Annex B (informative)

Guidance for the tensile testing of 9 % nickel steel weld metal using strain-gauged tensile specimens

B.1 Introduction

The all-weld metal tensile specimen from a thin butt-welded test plate is of such a small cross-sectional area that there is large variation in results. These results are not representative of the actual joint strength.

Since weld metal tensile properties for 9 % nickel steel do not exceed the tensile properties of the parent plate, it is necessary to obtain a value of weld metal proof stress and tensile stress to carry out an effective design.

The principle of this tensile test is that a localized spot, judged to be the weakest point in a welded joint, is measured while stressed in a similar manner to the service condition, i.e. transverse stress on a vertical joint due to the hoop stress.

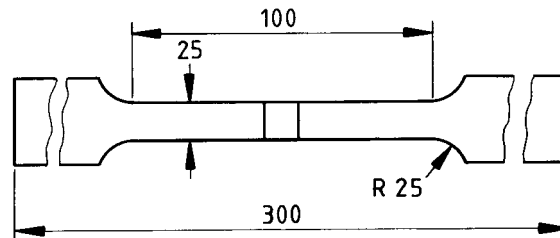
Since design is based on yield stress and tensile stress, the proof stress is measured by means of small gauge-length strain gauges on a joint tensile specimen from a test plate welded in accordance with the welding procedure to be used on the tank.

B.2 Method of testing

The method of testing should be as follows.

- a) The test specimens should be the full thickness of the plate at the welded joint, and in accordance with Figure B.1.
- b) The weld should be ground flush with the parent plate. There should be an adequate surface finish for strain gauge attachment.
- c) Misalignment should be a minimum.
- d) Flattening of the specimen should be carried out where necessary to achieve an angular misalignment of less than 1° .
- e) The strain gauges should be attached, using a recognized strain gauge adhesive, in accordance with Figure B.2.
- f) The strain gauges on either side should have equal length and characteristics. The maximum strain gauge length consistent with being completely within the weld metal surface width should be used.
- g) Initially, the gauges should be monitored independently when employing a preload, to check the gauge bonding and the extent of induced bending. If satisfactory, the gauges should be wired up with two dummy gauges mounted on similar weld metal, to eliminate the bending strains.
- h) Where there are strain gauges self-compensated for temperature, precision resistors may be used in the bridge circuit to replace the dummies. This should be in accordance with Figure B.3. The output is the sum of axial strain outputs from the two gauges on the specimen.

- i) The specimen should be loaded and the change in resistance of the strain gauges measured with equivalent loads, from which a stress/strain curve should be obtained.



All dimensions are in millimetres

Figure B.1 — Dimensions of tensile test specimen

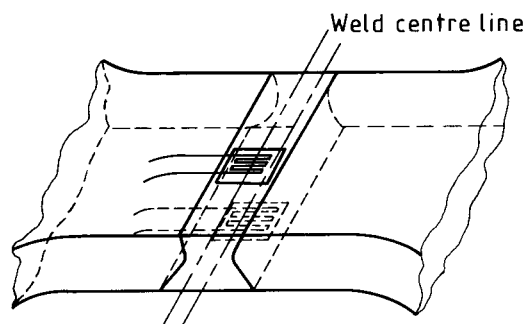


Figure B.2 — Method of attaching strain gauges

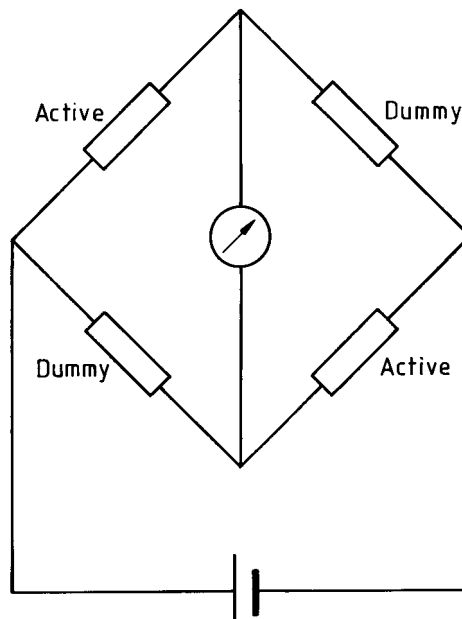


Figure B.3 — Test circuit

Annex C (informative)**Guidance for the use of aluminium and aluminium alloys for liquid containing tanks****C.1 Introduction**

The use of aluminium and aluminium alloys, though not specified in the standard, are acceptable for liquid-containing tanks, subject to agreement between the purchaser and the contractor.

In the event that aluminium or aluminium alloys are used, detailed evaluation of the complete design and construction requirements by experienced and competent personnel is necessary.

C.2 Materials

Materials should be in accordance with BS 1470, BS 1471 and BS 1474.

The maximum shell plate thickness should not exceed 55 mm.

Material in accordance with Table C.1 should be used for bolting aluminium and aluminium alloy components.

Table C.1 — Aluminium alloy bolting materials

Alloy	BS 1473	
AlMg5	5056A	H4
AlCu4SiMg	2014A	TF
AlSiMgMn	6082	TF

C.3 Design

When the bottom is lap welded, it should be welded on the top and bottom sides (see 7.2.3.2).

The use of a backing strip may produce unacceptable porosity or inadequate penetration due to improper cleaning. To ensure adequate quality it may be necessary to remove the backing strip and undertake repairs (see 7.2.3.2).

The maximum allowable design stress in service in any plate of the shell should be the least of UTS/2.67, 0.2 % PS/1.33 or 93 N/mm².

For the compression area, the maximum allowable compressive stress should be 44 N/mm² (see 7.1.5.5).

For NS8 aluminium alloy, the roof supporting structure should be designed in accordance with BS 8118-1 or CP 118 (see 7.1.5.3).

Manholes and shell nozzle bodies should not have a thickness less than that given in Table C.2 (see, also, 7.2.7).

Table C.2 — Manhole and shell nozzle thickness

Outside diameter d_n mm	Minimum manhole and nozzle body thickness t_p mm
$d_n \geq 50$	5
$50 < d_n \leq 70$	8
$70 < d_n \leq 100$	10
$100 < d_n \leq 200$	12.5
$200 < d_n \leq 300$	15
$300 < d_n$	20

C.4 Fabrication

Thermal cutting of aluminium and aluminium alloys is permitted only if plasma arc is used, followed, if necessary, by cleaning to sound metal (see 10.4).

C.5 Welding and testing

Welding processes should be metal inert gas, or tungsten inert gas without using flux.

Welding procedures should be in accordance with 11.12.3 of this standard and BS EN 288-4.

Welders should be approved in accordance with 11.12.4 of this standard and BS EN 287-2.

Radiographic techniques should be in accordance with BS 3451 (see, also, 11.13.1.4).

A section of weld which is shown by radiography to have linear porosity parallel to the axis of the weld, indicating a lack of fusion or lack of penetration, is unacceptable. This recommendation is in addition to the requirements of 11.13.1.

Annex D (informative)

Worked example of stiffener design for a fixed-roof container (see 7.1.4.3)

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

Course	h	t	H_e
1	2.5	9.0	2.5
2	2.5	9.0	2.5
3	2.5	9.0	2.5
4	2.5	9.5	2.184
5	2.5	9.5	2.184
6	2.5	9.5	2.184
7	2.5	10.0	1.921
8	2.5	10.0	1.921
9	2.5	10.5	1.700
10	2.5	11.0	1.514
11	2.5	11.0	1.514
12	2.5	11.5	1.355
13	2.5	11.5	1.355
14	2.5	11.5	1.355
Total $\Sigma H_e =$			26.687

Since $V_w = 55$ and $V_a = 6$, then $K = 6.663$.

$$\text{Whence } H_p = 6.663 \left(\frac{9^5}{48^3} \right)^{1/2} = 4.869.$$

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

These are located $\frac{CH_e}{6}$, $\frac{CH_e}{3}$, $\frac{CH_e}{2}$, $\frac{2CH_e}{3}$, and $\frac{5CH_e}{6}$ i.e 4.448 m, 8.896 m, 13.344 m, 17.791 m and 22.239 m, from the equivalent shell top.

First ring. The first ring is on a shell course of minimum plate thickness so no adjustment is needed. The remaining four rings are not on courses of minimum plate thickness, hence their positions relative to the *actual* top of the shell have to be determined.

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

$$1.396 \left(\frac{9.5}{9.0} \right)^{5/2} + (3 \times 2.5) = 9.098 \text{ m from the top of the shell.}$$

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

$$1.476 \left(\frac{9.5}{9.0} \right)^{5/2} + (5 \times 2.5) = 14.190 \text{ m from the top of the shell.}$$

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

$$1.818 \left(\frac{10.0}{9.0} \right)^{\frac{5}{2}} + (7 \times 2.5) = 19.866 \text{ m from the top of the shell.}$$

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

$$\frac{19.850 - (7 \times 2.5)}{\left(\frac{10.0}{9.0} \right)^{\frac{5}{2}}} = 1.806 \text{ m down on the eighth course.}$$

Therefore on equivalent shell = $17.791 - (1.818 - 1.806) = 17.779$ m.

Therefore remaining unstiffened equivalent shell = $26.687 - 17.779 = 8.908$ m.

Therefore one more ring is required at $17.779 + 8.908/2 = 22.233$ m

as $8.908/2 = 4.454 < H_p < 8.908$.

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

$$1.125 \left(\frac{11}{9} \right)^{\frac{5}{2}} + (10 \times 2.5) = 26.858 \text{ m from the top of the shell.}$$

The stiffening rings are, therefore, 4.418, 9.098, 14.190, 19.850 and 26.850 m from the top of the shell and are $150 \times 90 \times 10$ angle rings (see Figure 5).

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

List of references (see clause 2)

Normative references

BSI standards publications

BRITISH STANDARDS INSTITUTION, London

- BS 449, *Specification for the use of structural steel in building.*
- BS 449-2:1969, *Metric units.*
- BS 1501, *Steels for pressure purposes.*
- BS 1501-2:1988, *Specification for alloy steels: plates.*
- BS 1501-3:1990, *Specification for corrosion- and heat-resisting steels: plates, sheet and strip.*
- BS 1503:1989, *Specification for steel forgings for pressure purposes.*
- BS 1506:1990, *Specification for carbon, low alloy and stainless steel bars and billets for bolting material to be used in pressure retaining applications.*
- BS 1560, *Circular flanges for pipes, valves and fittings (Class designated).*
- BS 1560-3, *Steel, cast iron and copper alloy flanges.*
- BS 1560-3.1:1989, *Specification for steel flanges.*
- BS 2600, *Radiographic examination of fusion welded butt joints in steel.*
- BS 2600-1:1983, *Methods for steel 2 mm up to and including 50 mm thick.*
- BS 2654:1989, *Specification for manufacture of vertical steel welded non-refrigerated storage tanks with butt-welded shells for the petroleum industry.*
- BS 3603:1991, *Specification for carbon and alloy steel pipes and tubes with specified low temperature properties for pressure purposes.*
- BS 3605, *Austenitic stainless steel pipes and tubes for pressure purposes.*
- BS 3605-1:1991, *Specification for seamless tubes.*
- BS 3971:1980, *Specification for image quality indicators for industrial radiography (including guidance on their use).*
- BS 4592, *Industrial type metal flooring, waterways and stair treads.*
- BS 4592-1:1987, *Specification for open bar gratings.*
- BS 4592-2:1987, *Specification for expanded metal grating panels.*
- BS 4592-3:1987, *Specification for cold formed planks.*
- BS 4592-4:1992, *Specification for glass reinforced plastics open bar gratings.*
- BS 5289:1976, *Code of practice. Visual inspection of fusion welded joints.*
- BS 5950, *Structural use of steelwork in building.*
- BS 5950-1:1990, *Code of practice for design in simple and continuous construction: hot rolled sections.*
- BS 5950-2:1992, *Specification for materials, fabrication and erection: hot-rolled sections.*
- BS 5950-3, *Design in composite construction.*
- BS 5950-3.1:1990, *Code of practice for design of simple and continuous composite beams.*
- BS 5950-4:1982, *Code of practice for design of floors with profiled steel sheeting.*
- BS 5950-5:1987, *Code of practice for design of cold formed sections.*
- BS 5950-7:1992, *Specification for materials and workmanship: cold formed sections.*
- BS 5950-8:1990, *Code of practice for fire resistant design.*
- BS 6072:1981, *Method for magnetic particle flaw detection.*
- BS 6443:1984, *Method for penetrant flaw detection.*
- BS 7777, *Flat-bottomed, vertical, cylindrical storage tanks for low temperature service.*
- BS 7777-1:1993, *Guide to the general provisions applying for design, construction, installation and operation.*
- BS 7777-3:1993, *Recommendations for the design and construction of reinforced and prestressed concrete tanks and tank foundations, and the design and installation of tank insulation, tank liners and tank coatings.*

- CP 3, *Code of basic data for the design of buildings*.
 CP 3:Chapter V, *Loading*.
 CP 3:Chapter V-2:1972, *Wind loads*.
 BS EN 287, *Approval testing of welders for fusion welding*.
 BS EN 287-1:1992, *Steel*.
 BS EN 288, *Specification and approval of welding procedures for metallic materials*.
 BS EN 288-3:1992, *Welding procedure tests for the arc welding of steels*.
 BS EN 10025:1990, *Specification for hot rolled products of non-alloy structural steels and their technical delivery conditions*.
 BS EN 10028, *Specification for flat products made of steels for pressure purposes*.
 BS EN 10028-3:1993, *Weldable fine grain steels, normalized*.
 BS EN 10045, *Charpy impact test on metallic materials*.
 BS EN 10045-1:1990, *Test method (V- and U-notches)*.

Informative references

BSI standards publications

BRITISH STANDARDS INSTITUTION, London

- BS 1470:1987, *Specification for wrought aluminium and aluminium alloys for general engineering purposes: plate, sheet and strip*.
 BS 1471:1972, *Specification for wrought aluminium and aluminium alloys for general engineering purposes — drawn tube*.
 BS 1473:1972, *Specification for wrought aluminium and aluminium alloys for general engineering purposes — rivet, bolt and screw stock*.
 BS 1474:1987, *Specification for wrought aluminium and aluminium alloys for general engineering purposes: bars, extruded round tubes and sections*.
 BS 1501, *Steels for pressure purposes*.
 BS 1501-3:1990, *Specification for corrosion- and heat-resisting steels: plates, sheet and strip*.
 BS 3451:1973, *Methods of testing fusion welds in aluminium and aluminium alloys*.
 BS 4360:1990, *Specification for weldable structural steels*.
 BS 7777, *Flat-bottomed, vertical, cylindrical storage tanks for low temperature service*.
 BS 7777-4:1993, *Specification for the design and construction of single containment tanks for the storage of liquid oxygen, liquid nitrogen or liquid argon*¹⁾.
 BS 8118, *Structural use of aluminium*.
 BS 8118-1:1991, *Code of practice for design*.
 PD 6501, *The preparation of British Standards for building and civil engineering*.
 PD 6501-1:1982, *Guide to the types of British Standard, their aims, relationship, content and application*¹⁾.
 CP 118:1969, *The structural use of aluminium*.
 BS EN 287, *Approval testing of welders for fusion welding*.
 BS EN 287-2:1992, *Aluminium and aluminium alloys*.
 BS EN 288, *Specification and approval of welding procedures for metallic materials*.
 BS EN 288-4:1992, *Welding procedure tests for the arc welding of aluminium and its alloys*.

Other references

- [1] THE ENGINEERING EQUIPMENT AND MATERIALS USERS' ASSOCIATION (EEMUA). *Recommendations for the design and construction of refrigerated liquefied gas storage tanks*. EEMUA publication 147:1986¹⁾.
 [2] ROSE, R.T. Strength of reinforcements for manholes in welded storage tanks, *British Welding Journal*, October 1961.

¹⁾ Referred to in the foreword only.

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