

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 °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 × 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 ≥ 0	t ≤ 15	BS EN 10025:1990 Fe 430 B or Fe 510 B
	15 < t ≤ 35	BS EN 10025:1990 Fe 430 C or Fe 510 D1
T ≥ − 20	t ≤ 15	BS EN 10025:1990 Fe 430 B or Fe 510 C
	15 < t ≤ 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 $^{\circ}\text{C}$	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
$+10 > T \geq 0$	$t \leq 25$ $25 < t \leq 35$	BS EN 10025:1990 Fe 360 B, Fe 430 B or Fe 510 B BS EN 10025:1990 Fe 360 C, Fe 430 C or Fe 510 D1
$0 > T \geq -20$	$t \leq 12.5$ $12.5 < t \leq 20$ $20 < t \leq 35$	BS EN 10025:1990 Fe 360 B, Fe 430 B or Fe 510 B BS EN 10025:1990 Fe 360 C, Fe 430 C or Fe 510 C 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.

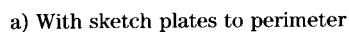
The minimum distance between individual three-plate joints shall be 300 mm.

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.*

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



All dimensions are in millimetres.

Figure 1 — Typical bottom layout for tank or container

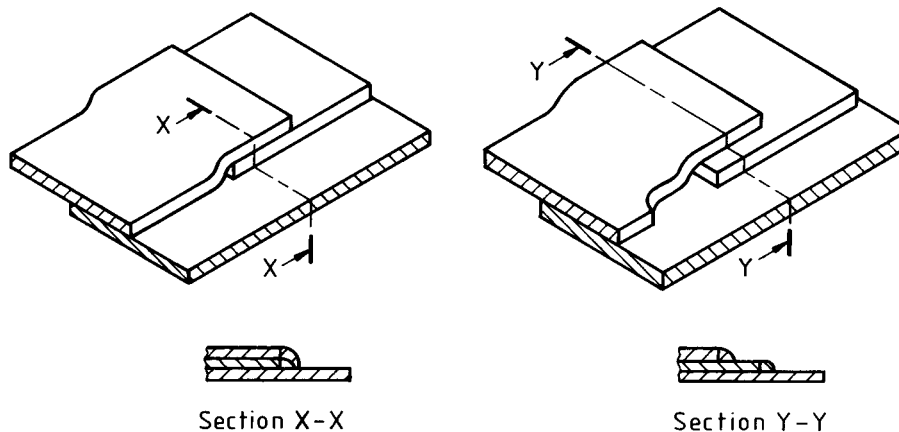
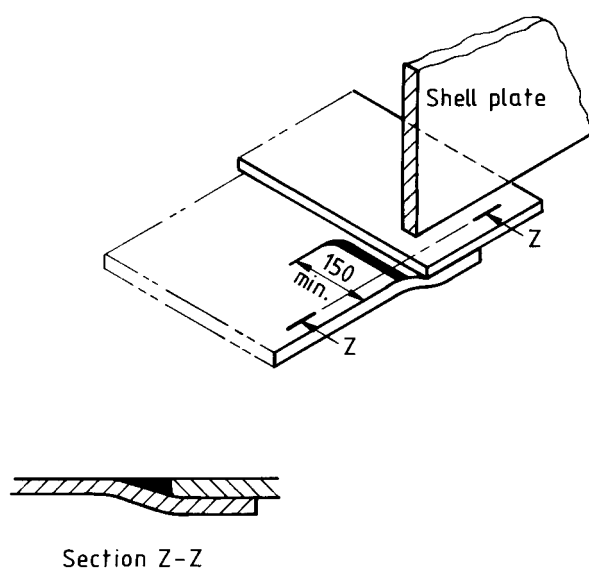
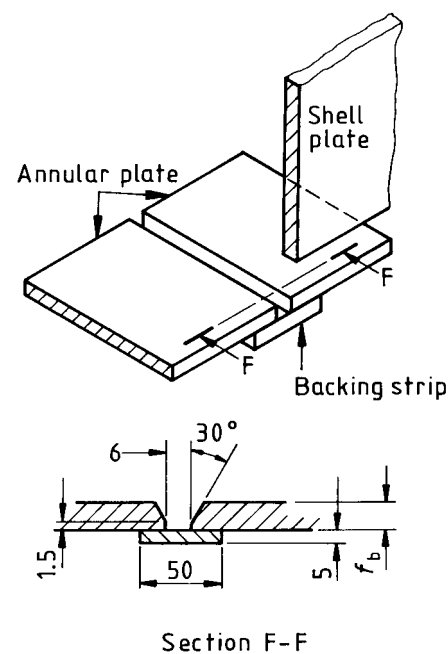


Figure 2 — Typical cross joints in bottom plates where three thicknesses coincide



Dimension is in millimetres.

Figure 3 — Typical sketch plate joint under shell plates for tank or container without annular plates



Linear dimensions are in millimetres.

Figure 4 — Typical annular plate joint under shell plates for tank or container with annular plates

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/mm² or two-thirds of the material minimum yield strength (in N/mm²) 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/mm²);
- D is the container diameter (in m);
- c is the corrosion allowance (in mm).

^a 1 mbar = 10⁻³ bar = 100 N/m² = 100 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:

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

where

- S_c is the allowable compressive stress (in N/mm²);
- t is the shell plate thickness at the point under consideration (in mm);
- c is the corrosion allowance, if applicable (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.

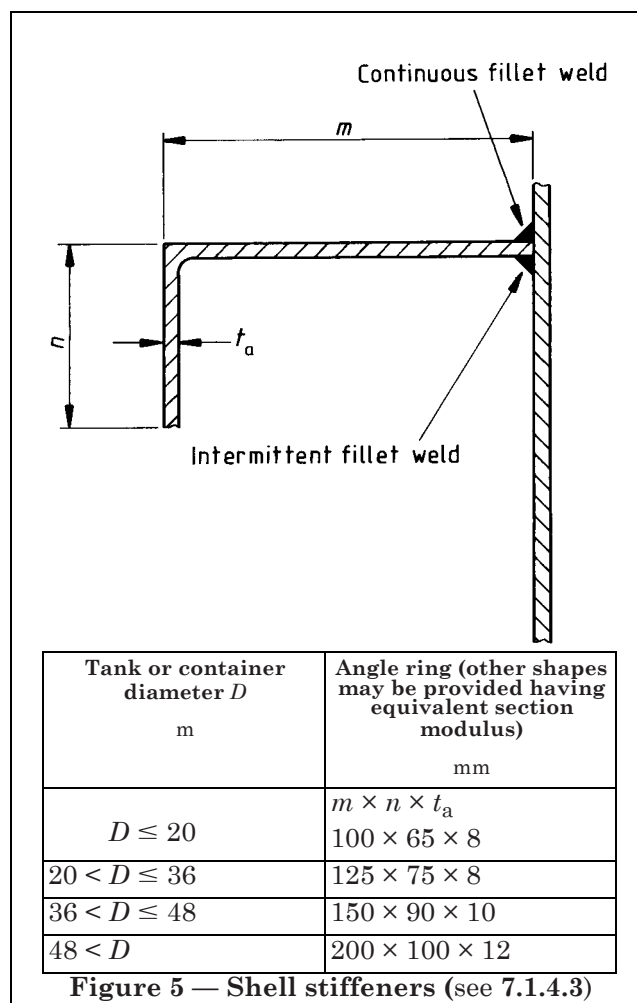
The fixing of shell stiffeners shall be in accordance with Figure 5.

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:

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

$$H_E = \Sigma H_e$$

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

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

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:

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

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);

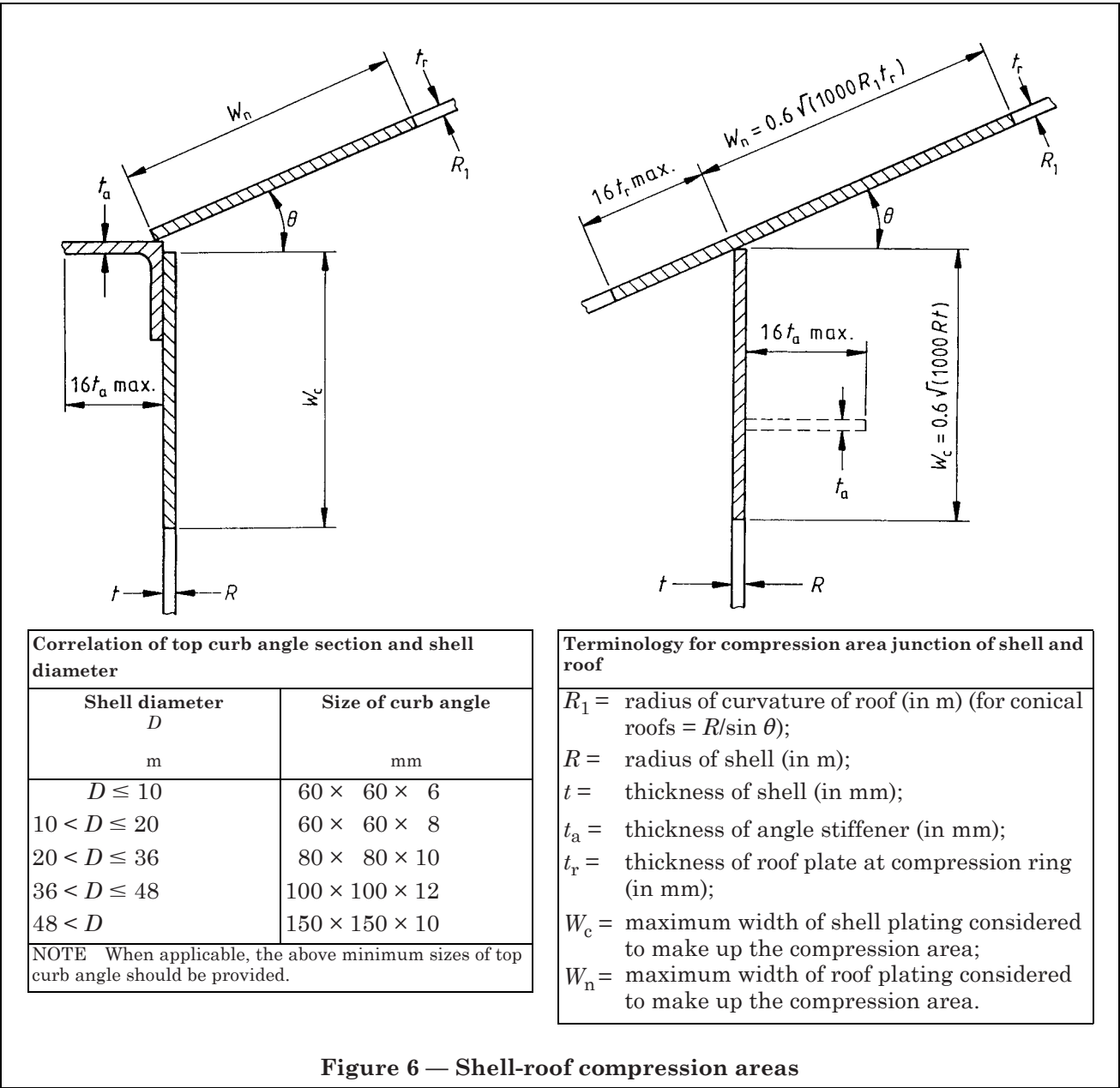
S_c is the allowable compressive stress (in N/mm²). This shall be taken as 120 N/mm².

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.



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/mm², 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.*

- a) 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.