Design and manufacture of site built, vertical, cylindrical, flat-bottomed steel tanks for the storage of refrigerated, liquefied gases with operating temperatures between 0 °C and –165 °C —

Part 3: Concrete components

The European Standard EN 14620-3:2006 has the status of a British Standard

ICS 23.020.10

British Standards

National foreword

This British Standard was published by BSI. It is the UK implementation of EN 14620-3:2006. This standard, together with BS EN 14620-4:2006, supersedes BS 7777-3:1993 which is withdrawn.

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This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard cannot confer immunity from legal obligations.

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Design and manufacture of site built, vertical, cylindrical, flat-bottomed steel tanks for the storage of refrigerated, liquefied gases with operating temperatures between 0 °C and -165 °C - Part 3: Concrete components

Conception et fabrication de réservoirs en acier à fond plat, verticaux, cylindriques, construits sur site, destinés au stockage des gaz réfrigérés, liquéfiés, dont les températures de service sont comprises entre 0 °C et -165 °C - Partie 3: Constituants béton

Auslegung und Herstellung standortgefertigter, stehender, zylindrischer Flachboden-Stahltanks für die Lagerung von tiefkalt verflüssigten Gasen bei Betriebstemperaturen zwischen 0 °C und -165 °C - Teil 3: Bauteile aus Beton

This European Standard was approved by CEN on 20 February 2006.

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CEN member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the Central Secretariat has the same status as the official versions.

CEN members are the national standards bodies of Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom.

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Foreword

This European Standard (EN 14620-3:2006) has been prepared by Technical Committee CEN/TC 265 “Site built metallic tanks for the storage of liquids”, the secretariat of which is held by BSI.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by March 2007, and conflicting national standards shall be withdrawn at the latest by March 2007.

EN 14620 *Design and manufacture of site built, vertical, cylindrical, flat-bottomed steel tanks for the storage of refrigerated, liquefied gases with operating temperatures between 0 °C and -165 °C* consists of the following parts:

— Part 1: General;

— Part 2: Metallic components;

— Part 3: Concrete components;

— Part 4: Insulation components;

— Part 5: Testing, drying, purging and cool down.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom.

1 Scope

This European Standard specifies general requirements for materials, design and construction of the concrete components of the refrigerated liquefied gas storage tanks.

This European Standard deals with the design and manufacture of site built, vertical, cylindrical, flat-bottomed steel tanks for the storage of refrigerated, liquefied gases with operating temperatures between 0 °C and –165 °C.

2 Normative references

The following referenced documents are indispensable for the application of this European Standard. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 206-1, *Concrete — Part 1: Specification, performance, production and conformity*

EN 1992-1-1:2004, *Eurocode 2: Design of concrete structures — Part 1-1: General rules and rules for buildings*

EN 1992-1-2:2004, *Eurocode 2: Design of concrete structures — Part 1-2: General rules — Structural fire design*

EN 14620-1:2006, *Design and manufacture of site built, vertical, cylindrical, flat-bottomed steel tanks for the storage of refrigerated, liquefied gases with operating temperatures between 0 °C and –165°C — Part 1: General*

EN 14620-2, *Design and manufacture of site built, vertical, cylindrical, flat-bottomed steel tanks for the storage of refrigerated, liquefied gases with operating temperatures between 0 °C and –165 °C — Part 2: Metallic components*

3 Terms and definitions

For the purposes of this European Standard, the terms and definitions given in EN 14620-1:2006 and the following apply.

3.1
low temperature
temperature lower than –20 °C

4 General

For material selection and design of normal reinforced concrete and/or pre-stressed concrete structures, reference is made to EN 1992-1-1.

5 Vapour tightness

To ensure vapour tightness of the outer tank (e.g. in a full containment tank) metallic liners or polymeric coatings shall be used.

6 Materials

6.1 General

Material properties of concrete and components change at low temperature. Some changes are beneficial, some non-beneficial. The appropriate material properties shall be used to ensure that the structural integrity is not impaired for all temperature ranges for the components. This shall include both steady state and transient conditions.

NOTE Low temperature resistant material requirements, as given in 6.2 to 6.3, are needed only as far as they are required to guarantee the structural integrity and to fulfil the liquid tightness and where applicable vapour tightness requirements.

6.2 Concrete

For normal and low temperature conditions, the concrete material requirements shall be in accordance with EN 1992-1-1.

For the concrete performance, production, placing and compliance criteria, reference shall be made to EN 206-1.

NOTE Further information about the low temperature performance of concrete components is given in Annex A.

6.3 Pre-stressing and reinforcing steel

6.3.1 Pre-stressing steel and anchors

Pre-stressing steel, anchors, ducts etc. shall be in accordance with EN 1992-1-1.

In addition, it shall be demonstrated that the pre-stressing steel and anchors are suitable for the cold temperatures to which it may be exposed.

NOTE Further information about the low temperature performance of pre-stressing concrete is given in Annex A.

6.3.2 Reinforcing steel

For the design of reinforced concrete structure where the design temperature during a normal operating or emergency condition does not fall below –20 °C, the reinforcing steel shall comply with EN 1992-1-1.

For elements under tension, where the design temperature during a normal operating or emergency condition falls below –20 °C, additional low temperature requirements shall be implemented.

NOTE Guidance is given in Annex A.

It shall also be demonstrated that reinforcement connectors, used at ambient temperature, are suitable for the intended application.

For low temperature, the connectors shall be subjected to the same tests at design metal temperature and the results of these tests shall be compared to those at ambient temperature. The connectors shall be considered suitable if the low temperature results are within 5 % of those specified at ambient temperature. The contractor shall carry out appropriate tests, which shall include, as a minimum, tests for tensile strength and ductility. The results of these tests shall meet appropriate criteria set by the designer.

7 Design

7.1 General

Actions to be considered shall be in accordance with EN 14620-1:2006.

The reliability of the concrete components, according to the limit state theory, shall be achieved by application of the partial factor method.

The design values of actions, the effects of actions, material properties, geometric data and the design resistance shall be determined in accordance with EN 1992-1-1. In case heat radiation is involved, reference shall be made to EN 1992-1-2.

7.2 Partial factors for actions and combinations of actions

Table 1 provides partial load factors for accidental actions. They shall be used in addition to the partial load factors mentioned in the EN 1991-1-1.

Table 1 — Partial load factors for accidental actions

Load combinations	Load factors					
	Dead		Imposed		Abnormal load	Wind
	Adverse	Beneficial	Adverse	Beneficial		
Normal action plus one accidental action	1,05	1,0	1,05	0	1,0	0,3
Accidental actions being, earthquake (SSE), blast overpressure, external impact, fire or leakage from inner tank.						

7.3 Liquid tightness

For liquid tightness, the following shall be considered:

a) **In case of a non-liquid tight liner/coating**

For concrete outer containers without a liquid tight liner or coating, the liquid tightness of the concrete shall be ensured by means of the minimum compression zone of 100 mm.

b) **In case of a liquid tight liner/coating**

Where a liquid tight liner/coating is applied (to ensure full tightness of the secondary container) then cracking of the concrete section shall be permitted within the limits specified by EN 1992-1-1.

In such cases the crack width shall be calculated and the liner/coating shall be proven to be capable of ‘bridging’ a gap equal to 120 % of the crack width.

8 Detailing provisions

8.1 General

For general information on pre-stressed concrete tanks, reference should be made to Annex B.

8.2 Pre-stressing

For the pre-stressed concrete wall, horizontal pre-stressing shall be applied.

NOTE Vertical pre-stressing is not required. It can be combined with horizontal pre-stressing. The need for vertical pre-stressing depends on the tank design pressure, tank diameter, and associated permanent and transitional stresses within the concrete section.

8.3 Wall design

The minimum wall thickness shall be determined so that:

— adequate cover to all reinforcement and pre-stressing tendons shall be available;

— space between the reinforcement and pre-stressing tendons shall be sufficient to ensure that a homogeneous, liquid tight concrete structure is obtained.

8.4 Steel roof liner

The steel roof liner shall be anchored adequately to the concrete roof.

NOTE The liner may act as formwork for the concrete and may also act compositely with the use of shear studs. The concrete may be built up in layers to prevent overstress of the liner (see also B.6)

8.5 Construction joints

Attention shall be paid to the design and execution of the construction joints. The location and necessity shall be carefully planned to minimize the risk of poor jointing. For the areas where liquid tightness is to be assured, the contractor shall provide method statements based on proven working practices and where necessary, due to lack of evidence, the contractor shall carry out tests to demonstrate that the construction joint is liquid tight.

8.6 Position of tendons and wires

For internal pre-stressing systems using buttresses and grouted tendons, due account of the emergency conditions, e.g. fire scenarios, shall be taken to determine the position of the pre-stressing system.

NOTE 1 Tendons should be preferably placed, in the centre of the concrete wall for protection against external fires.

The tendons shall be well protected from corrosion during the life of the tank. Grouting procedures shall be provided and agreed between the designer and contractor to provide adequate protection to the tendons.

NOTE 2 In very aggressive environments, where additional protection is required, for the tendons, non-ferrous pre-stressing ducts may be considered. Reference is made to 'Durable bonded post-tensioned bridges' Concrete Society Report TR47 [12]. For non-bonded tendons, reference should be made to FIP recommendation 91 [13].

NOTE 3 Where wire-winding systems are used the wire should be placed on the outer face of the wall in a continuous helix with vertical spacing between wires of not less than 8 mm. Each layer of wire should be coated with shotcrete to provide a minimum of 6 mm thickness over the wire. After all the wires have been placed and coated, a final coating of shotcrete should be applied to provide a minimum thickness of 25 mm over the last wire.

8.7 Concrete cover

The concrete cover selection of reinforcement shall take into account the exposure classification, soil conditions and emergency design conditions e.g. fire protection.

Minimum requirements shall be in accordance with EN 1992-1-1.

8.8 Minimum reinforcement

The minimum area of reinforcement shall be in accordance with EN 1992-1-1.

8.9 Reinforced concrete bund walls

Bund walls constructed in reinforced concrete shall be permitted. The bund wall shall be designed to the requirements specified in this European Standard.

NOTE Bund walls are required with a single containment tank. They can be applied in combination with an earth embankment for structural reasons.

9 Construction and workmanship

9.1 General

In principle, the construction and workmanship requirements shall be in accordance with EN 1992-1-1.

Special attention shall be paid to the concrete composition, production, quality control, placement, compaction, curing etc. of the concrete to ensure liquid tightness of the structure, which shall be in accordance with EN 206-1.

In addition, the following requirements shall apply.

9.2 Crack control

The contractor shall investigate the heat of hydration and the effects of drying and thermal shrinkage in the concrete structure. The composition of the mix, the cement type, and the intended execution method shall be adapted accordingly so that cracking of the concrete is minimized.

Temperature differences between new and old constructions and the environment shall be considered in the construction plan.

9.3 Formwork and tie-rods

The formwork shall be tightly sealed at all joints. Calculations of the formwork shall be made to ensure sufficient strength and stiffness.

Special arrangements shall be applied at tie-rods to prevent leakage.

All cone openings shall be sealed such that liquid tightness shall be ensured.

9.4 Spacers

Spacers shall be used to provide correct cover to the reinforcement and they shall be product resistant and liquid tight.

9.5 Curing

Curing shall be performed in accordance with EN 206-1.

NOTE Curing is dependent on many factors including wind speed and temperatures of the air and concrete mix.

The curing period shall include measures to prevent excessive evaporation and to stabilize the temperature effects caused by heat of hydration until the concrete matrix gains sufficient internal strength to withstand both internal and external stresses incurred.

9.6 Tolerances

General tolerance requirements of the concrete structure shall be in accordance with EN 1992-1-1. The contractor shall investigate the necessity for stricter tolerances e.g. special linings and for certain insulation systems (membrane tanks).

10 Liners and coatings

10.1 General

Liners and coatings shall be applied on the concrete internal surface in order to avoid moisture and vapour penetration through the structure.

NOTE Liners and coatings may also be used to ensure liquid tightness of the structure.

The following materials shall be used:

— steel plates as liners;

— reinforced or un-reinforced polymeric layers as coatings.

10.2 Liners

Steel liners shall be considered vapour and liquid tight as long as the material selection is appropriate. The material selection shall be based on the design metal temperature to be determined by the contractor. Steel type selection shall be made in accordance with EN 14620-2.

The minimum thickness of the plate shall be 3 mm.

Any creep or long-term deformation of the concrete due to operational conditions applied to the structure shall be taken into account for the design of the liner.

The anchoring system shall be designed for combined shear and tension.

10.3 Coatings

Liners or coatings shall be applied as vapour barrier or as vapour/liquid barrier. The coatings shall be applied directly to the concrete surface. Prior to application, the concrete surfaces shall be grit blasted and subsequently vacuum cleaned. All remains of release agents and curing compounds shall be removed if these are not compatible with the coating system.

When the coating functions as a vapour barrier, the following shall apply:

— maximum water vapour permeability shall be 0,5 g/m^2 24 h.

NOTE 1 The recommended test method is ASTM E96 under temperature/humidity conditions equal to the climatic conditions of the location of the project.

— coating shall not degrade after long-term contact with the product (vapour).

NOTE 2 The recommended test method is immersion in product vapour for at least three months.

— coating shall not deteriorate under the influence of the concrete. The coating shall be alkali resistant.

NOTE 3 The recommended test method is ASTM D1647 or equivalent.

— bond strength of the coating to concrete shall exceed 1,0 MPa.

NOTE 4 The recommended test method is EN ISO 4624 or equivalent.

— escape of vapour shall be limited. This shall be considered acceptable when the permeability of product vapour is restricted to 0,1 g/m^2 24 h;

— coating shall have sufficient flexibility to be capable of bridging crack widths. A bridging capability value of 120 % of the calculated design crack width at normal operating temperatures shall be used.

NOTE 5 The test method should be proposed by the contractor.

Where the coating also acts as a liquid barrier, additional tests shall be performed. The contractor shall demonstrate that the coating does not degrade after short time (splashing) and long time (three months) liquid exposure.

10.4 Thermal Protection System (TPS)

When a TPS is applied, the following subjects shall be considered:

— all possible actions, including hydrostatic pressure of the product, vapour pressure, effects of creep and shrinkage of the concrete and steel plate;

— adequate liquid tightness of the wall section at the top (concrete cracking);

— sufficient height of the wall section.

The height of the wall section shall be at least 500 mm above any temporary construction opening.

Annex A
(informative)

Materials

A.1 Concrete

For concrete, the following general information is provided:

— for pre-stressed concrete the class of concrete should be at least f_{ck} 40 of EN 1992-1-1:2004;

— enhanced strength, that is known to exist for concrete as a material of construction at low temperature, is normally not used in determining the ultimate strength of concrete sections. However, when adequate testing data is available, the low temperature properties may be utilized;

— reduced expansion coefficient, thermal properties and Young's modulus should be considered for design verification;

— strength increase caused by high strain rates (e.g. valve impact) should be considered when appropriate;

— use of high strength concrete and/or fiber admixtures may be considered appropriate for certain applications;

— use of a low water/cement ratio is essential. It reduces the pore water within the concrete matrix. The freezing of pore water causes an expansion of about 9 %. Some of this expansion is taken up within existing air voids but, if there is excessive water, internal cracking of the concrete can result;

— concrete mix may contain up to 5 % entrained air. Air entraining agents should be resin based in accordance with the relevant standard. Metallic based agents should not be used;

— it should be ensured that no adverse effects from using combinations of concrete additives can take place;

— ground granulated blast furnace slag or pulverised fuel ash may be used in combination with Portland cement. These materials assists in reducing the heat of hydration of thick concrete sections and thus reducing the early thermal shrinkage;

— whilst the introduction of cement replacement materials may be beneficial in terms of the reduction of early shrinkage and enhanced resistance to environmental pollution, users should be aware that there may be a slower strength gain;

— prolonged contact with hydrocarbon products has no significant detrimental effect on the properties or useful life of concrete, even at ambient temperatures;

— microsilica may be considered to improve the resistance to corrosion.

A.2 Pre-stressing steel and anchors

For the design of pre-stressed concrete structures the following information is provided:

— greatest load to the concrete structure occurs during construction, when the tensile load is applied to the pre-stressing steel tendons or bars. The jacking stress in the steel tendon is around 80 % of the yield strength of the tendons. Thereafter the applied stress to the steel tendons reduces due to lock-off, transfer, relaxation and creep. This forms part of the reason why hydrostatic testing is not required for the secondary container of double and full containment tanks;

— pre-stress losses and numerical values are ascertained for the steel at ambient temperature as a conservative assessment as the steel characteristics improve at low temperature;

— if the design temperature is lower than 50 °C, then it should be demonstrated by testing that the pre-stressing system (bars, strands and anchors) is suitable for the cold temperatures to which it may be exposed. In this respect the following literature should be considered:

1) "cryogenic behaviour of materials for pre-stressed concrete" [14];

2) "Assessment of mechanical properties of structural materials for cryogenic applications" [15].

A.3 Reinforcing steel

A.3.1 Sampling

For the testing of the bars, fully finished bar should be sampled from two production heats, from the maximum and minimum bar diameter for the order, and from all strength grades to be used. The minimum rate of specimen testing should be in accordance with EN 10002-1. Testing should be carried out in accordance with EN 10080 where test records are not available from the manufacturer.

A.3.2 Testing

Tensile tests should be carried out under cold condition (at the design metal temperature) to establish the suitability of the steel.

NOTE The design metal temperature should be the lowest temperature that the reinforcement bar would be subjected to under abnormal loading conditions.

During the test, the specimen temperature should be as uniform as possible. The difference between the temperature at any two points of the specimen or the difference between the temperature at any point and the design temperature should not exceed 5 °C.

Tensile tests in accordance with EN 10002-1 should be conducted on un-notched and notched bar specimens.

The following criteria should apply:

1) The Notch Sensitivity Ratio (NSR) should be:

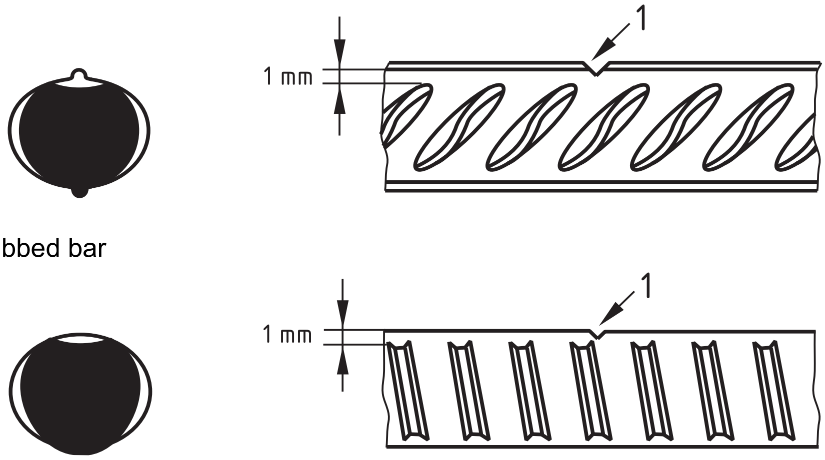
$$\mathrm{NSR} = \frac{\text{Tensile strength of notched bar}}{\text{0,2\% proof stress of unnotched bar}}$$

or:

$$\text{NSR} = \frac{\text{Tensile strength of notched bar}}{\text{Lower yield stress of unnotched bar}}$$

A NSR value of 1 or greater is required to achieve acceptable toughness.

The test specimen for notched bar tests should be notched at the half-length position between the machine grips. A V-notch should be used that has an internal angle of 45° and a radius at the base of 0,25 mm. Machining techniques and tolerances should be in accordance with EN 10045-1. For longitudinal ribbed bars, the notch should be placed across the rib and penetrate 1 mm into the underlying bar. For transverse ribbed bars, the notch should be placed on the crown (see Figure A.1).



a) longitudinal ribbed bar

b) transverse ribbed bar

Key

1 V-notch

Figure A.1 — Notch on reinforcement bar

2) Plastic elongation

Each un-notched specimen should demonstrate a percentage plastic elongation of at least 3 %. The percentage plastic elongation is the permanent percentile increase of the original gauge length corresponding to tensile strength.

3) Yield strength

In addition, the yield strength of the un-notched specimen found during testing should be at least 1,15 times the minimum yield strength used in the design.

A.3.3 Alternative solutions

The following alternatives may be considered:

— use of carbon-manganese steel, 9 % nickel steel or austenitic stainless steel. Various grades of stainless steel reinforcement are available complying with EN 10088-1. The ductility of most austenitic stainless steels is maintained down to –196 °C;

— reinforcing or pre-stressing steel with reduced allowable tensile stress.

NOTE ANSI/NFPA 59A recommends a maximum allowable tensile stress for reinforcement for tanks for LNG. This is significantly lower than the stress permitted for ambient temperature, and may result in an uneconomic design, but can be justified where special steel is not available or economically unacceptable.

Annex B
(informative)

Pre-stressed concrete tank

B.1 General

The following publications give reference information on details and parameters for the design of prestressed concrete tanks:

— Turner F.H. Concrete and cryogenics [16];

— Bruggeling, A.S.G. Prestressed concrete for the storage of liquefied gases [17];

— Preliminary recommendations for the design of prestressed concrete containment for the storage of refrigerated liquefied gases [18].

Pre-stressed concrete is most suitable for liquid tight concrete structures. Therefore, it is used for the wall of the tank. The bottom and the roof are often made of normal reinforced concrete.

B.2 Pre-stressing system

Horizontal pre-stressing is always required. The need for vertical pre-stressing depends on the design of the tank (design pressure, thickness of roof etc.).

Horizontal pre-stressing could be provided by means of the following techniques:

— horizontal tendons positioned in ducts within the concrete wall of the tank, extending between the buttresses formed on the outer face of the tank wall;

— an aggregation of tendons formed by winding wire or strand around the outer face of the wall.

NOTE Wire winding systems should be placed on the outer face of the wall in a continuous helix with vertical spacing between wires of not less than 8 mm. Each layer of wire should be coated with shotcrete to provide a minimum of 6 mm thickness over the wire. After all wires have been placed and coated as described, a final coating of shotcrete should be applied to provide a minimum thickness of 25 mm over the last layer of wire (AWWA D110).

B.3 Base slab

The tank base slab could be made of either pre-stressed or reinforced concrete.

In the case of pre-stressed concrete where piles are used, movement of the slab from pre-stress forces shall be considered in the design.

NOTE Often the base slab is made in sections with construction joints. Full attention should be paid to the execution of the construction joints so that a monolithic structure is ensured.

B.4 Wall to base junction

The wall to base connection could be designed as a:

- fixed joint: in such a case the concrete structure is monolithic. The movement of the wall, relative to the base slab, is prevented. The joint is designed to accept the relatively large moments and shears which arise as a consequence;
- sliding joint: the wall is supported by the base slab and may move horizontally. The wall is free to move horizontally. It is supported by the base slab. Generally it is necessary to ensure that the outer tank cannot move laterally. Radial guides should be provided to ensure that the movement is concentric with the base slab. A flexible seal, commonly in the form of a stainless steel strip, should be provided to prevent leakage of liquid or gas;
- pinned joint: the wall is also supported by the base slab, it is fixed horizontally, (usually after post tensioning) and has the capability of limited rotation. Substantial shear is transferred from wall to base slab, but the joint is not required to transmit bending moments. The custom is to allow the wall to slide while it is being pre-stressed. Thereafter it is pinned in position, by one of several devices, but not prevented from vertical rotation.

A summary of the advantages and disadvantages of each type of joint is given in Table B.1.

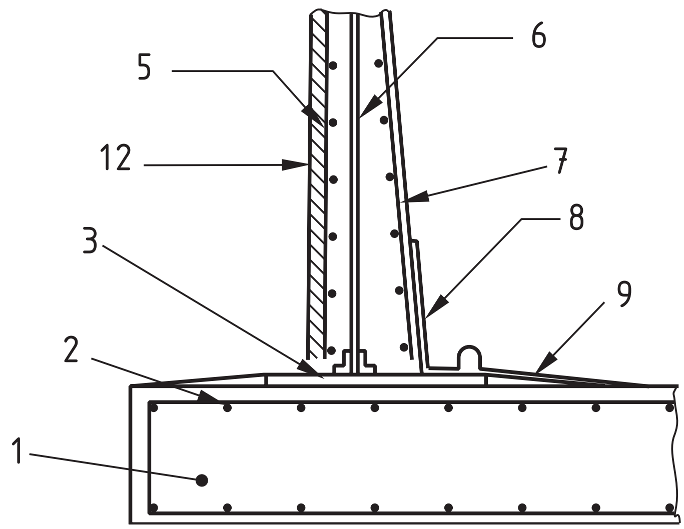
Table B.1 — Summary of the advantages and disadvantages of joints in the wall to base junction

System	Advantages	Disadvantages
Sliding joint	Stresses are predicted with good reliability Secondary stresses are relatively small	Dependent on adequacy of joint seal Some uncertainty over degree of sliding obtained
Pinned joint	Pre-stress is predicted with good reliability Maximum moment occurs in wall away from the joints, at level where "end effects" from vertical tendons are largely smoothed out	Subsequent secondary stresses are less reliable Large shears and fairly large moments
Fixed joint	Robust form of construction Full vertical pre-stressing in bottom of wall	Larger moments and shears Maximum moment occurs at the joint

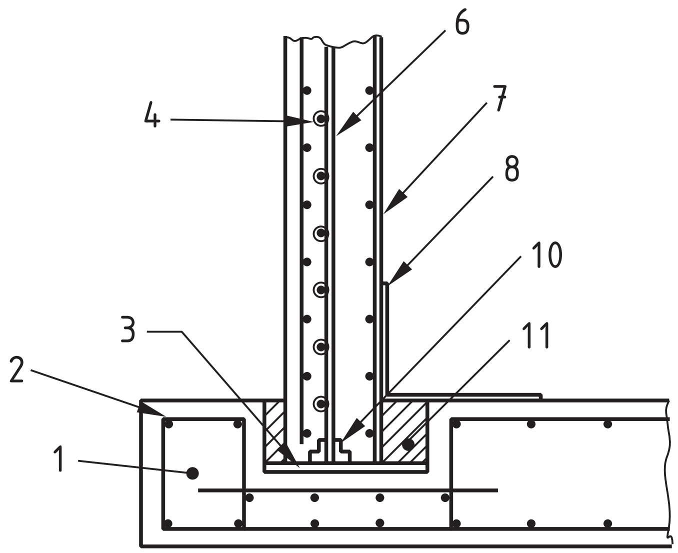
The fixed joint concept is preferred for liquid tightness.

For LPG tanks, the fixed joint can be designed for the low temperature to which it may be exposed in case of a primary container leakage. This is not the case for LNG tanks. The wall to base connection has to be protected by TPS.

The three different designs of joint are shown in Figure B.1.

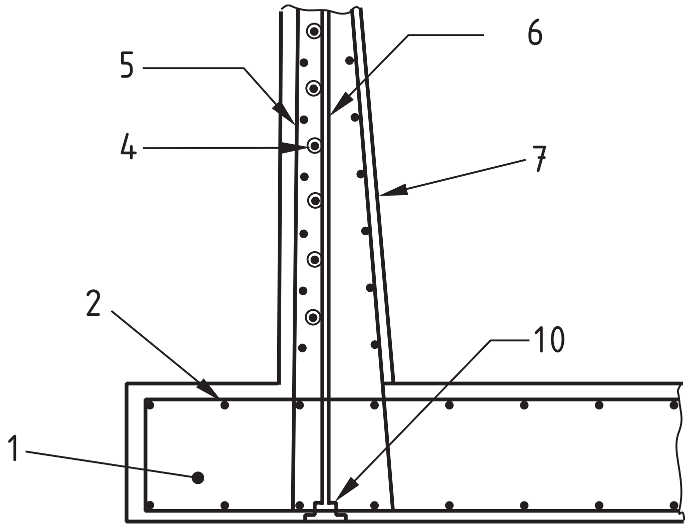


a) Sliding joint



b) Pinned joint

Figure B.1 — Typical joints for pre-stressed wall and base junction



c) Fixed joint

Key

1	tank base	7	pre-stressed wall
2	base reinforcement	8	stainless/nickel steel seal
3	bearing plate	9	radial strap
4	circumferential pre-stress	10	pre-stressing anchorage
5	wall reinforcement	11	grout
6	vertical pre-stress	12	wire wound circumferential pre-stress with shotcrete layer

Figure B.1 — Typical joints for pre-stressed wall and base junction (*concluded*)

B.5 Wall to roof junction

The wall to roof connection is usually made of a monolithic construction.

B.6 Roof

The use of a concrete roof is usually advantageous in case a high design pressure (design pressure > 140 mbar for example) is applied.

The roof is normally made of reinforced concrete. An internal steel liner is used to ensure the vapour tightness of roof. This liner can be used as formwork and may act as a composite structure. In this case, the liner is anchored to the concrete by studs.

The roof can be cast continuously (ring bands) or can be divided into a number of sections. The roof can also be cast in several layers, depending on its thickness. Attention should be paid to the construction method adopted for, flat and crack-free, finishing of the roof. The concrete production rate, transport capacity and workforce and the slope of the roof are aspects to be considered.

During the concreting, an air pressure inside the tank might be necessary to support the fresh concrete weight until sufficient resistance is reached.

B.7 Foundation design

B.7.1 General

The following types of foundation can be considered:

— shallow foundation (raft or ring beam type);

— piled foundation.

B.7.2 Shallow foundation

B.7.2.1 Raft system

Where soils have the necessary properties to support designated loading, a soil supported reinforced concrete slab can be considered. The slab should be sized to provide an adequate spread of load to the soil and may require thickened sections for highly loaded areas e.g. under the tank shell and walls. In the design of the slab, provision should be made for the effects of local differential settlement, drying shrinkage, creep and thermal strain during service or under emergency conditions.

B.7.2.2 Ring beam system

Where the soil can support the applied loads from the tank and contents within allowable settlements, a tank-pad type foundation could be considered. This is augmented by a structurally independent ring beam designed to support the tank shells and/or walls and to provide anchorage to resist uplift.

Attention should be given to the design of the ring beam to tank-pad interface, to avoid a sharp change in bearing medium. A transition support plate may be required.

NOTE A separate ring beam may also be provided within the tank to provide a load bearing insulating support for the inner tank shell. This is in addition to any main foundation ring beam.

Where the soil conditions do not permit a near surface soil supported foundation, the base should be supported on piles.

B.7.3 Piled foundation

Piles or piers should be used to provide adequate foundation capacity from the deeper soil strata. The use of piles is often based on economic justification, and the wide variety of options for pile types, diameters and lengths has many advantages to optimize the foundation design.

The base design should take account of variations in pile stiffness. The installation method and pile capacity shall be verified through a pre-production and production-testing program. Consideration should be given to designing the base and pile system to accommodate a redistribution of load in the event of failure of an individual pile.

NOTE 1 Attention should be paid to the possibility of cooling down of the base slab due to leaks in the primary container. Shrinkage of the slab should be taken into account. The shrinkage will decrease towards the centre of the slab.

NOTE 2 Consideration should be given to the joint between pile supports and the base. If the subsoil characteristics are suitable, closely spaced slender piles can be rigidly connected to the base. Where large diameter in-situ formed piles are used, it may be possible to use rigid connections for the piles near the centre of the tank, but to provide a sliding joint for the remainder.

NOTE 3 The horizontal force that may be specified for blast loading is an important aspect to be considered in case piles are used.

NOTE 4 In a double or full containment tank, horizontal forces and moments from accidental actions may also be transferred to the base slab.

The use of an elevated slab can also be considered. Major considerations are the use of ‘accessible’ vibration isolators (against earthquake loading) or to avoid the use of heating elements.

The paving under the tank should slope to the edge of the tank so that in case of a spill product is diverted to the outside.

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