

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

**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**

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 Insulations 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 in accordance with 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 and 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 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.*

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 iv, pages 1 to 26, 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 provides recommendations for the design and construction of prestressed concrete components, reinforced concrete components, foundations, insulation, linings and coatings. The recommendations are applicable to single, double or full containment tanks for above ground installation at service temperatures down to $-165\text{ }^{\circ}\text{C}$, and single containment tanks down to $-196\text{ }^{\circ}\text{C}$.

Guidance on design criteria for concrete structures, prestressed concrete and prestressing losses for concrete members is given in Annex A, Annex B and Annex C.

NOTE A bibliography is included as Annex D.

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 26. 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 26, but reference should be made to the latest editions.

3 Definitions

For the purposes of this Part of BS 7777, the definitions given in BS 7777-1:1993 apply.

4 Design conditions

Tanks should be designed to suit the pressures that are met in service. Unless otherwise agreed between the purchaser and the manufacturer the internal positive pressure should be not greater than $140\text{ mbar}^{1)}$ (gauge), and the internal negative pressure should be not greater than 6 mbar (gauge).

NOTE 1 The internal positive pressure of 140 mbar (gauge) may be exceeded subject to agreement between the purchaser and contractor, but for large diameter tanks the design of the roof to shell joint and anchorage might be limiting (see BS 7777-4).

NOTE 2 For tanks with concrete roofs the internal positive pressure of 140 mbar (gauge) may be exceeded because of increased dead weight.

The lowest service temperature permitted is $-165\text{ }^{\circ}\text{C}$ for tanks conforming to BS 7777-2 and $-196\text{ }^{\circ}\text{C}$ for tanks conforming to BS 7777-4.

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

5 Information to be exchanged between the purchaser and the contractor

Information to be exchanged between the purchaser and contractor should be as given in clause 5 of BS 7777-1:1993.

6 Materials

6.1 General

All materials utilized should be in accordance with the recommendations of this Part of BS 7777. If alternative materials are utilized, they should conform to written standards and have at least the minimum properties given in the British Standards referred to in 6.2 to 6.7. The use of alternative materials should be agreed between the purchaser and the contractor.

6.2 Materials for prestressing steel and anchors

NOTE Prestressed concrete is a form of reinforced concrete, which is a heterogeneous material, that is maintained in a state of compression as a result of the tensile forces applied to the prestressing steel tendons within the concrete structure. Residual compression of the concrete is necessary under service load conditions.

The greatest load to the concrete structure occurs during construction, when the tensile load is applied to the prestressing steel tendons or bars. The jacking stress in the steel tendon is normally 65 % to 75 % of the ultimate tensile strength.

Thereafter the applied stress to the steel tendons reduces due to lock-off, transfer, relaxation and creep.

The prestressing losses are calculated to determine the residual stress in the tendon (see Annex C).

Normally prestressed concrete for refrigerated liquid gas (RLG) containments utilizes a fully bonded system between the tendons and the concrete. This takes the form of either cementitious grouting of ducts after stressing the tendons or applying a sprayed or pneumatic concrete coating to an externally wire wound prestressing system. It is essential that a reliable system of bonding is utilized and that no likelihood of slippage of the tendon, or any part of it, is envisaged at the design temperature. From test results it is seen that considerable ductility is retained in prestressing tendons at low temperature. Notch toughness can be reduced but there is no risk of a failure being propagated to adjacent bars or strands of a tendon. Furthermore, within a short distance of a failed bar or strand, full strength is regained because of the bond between the steel and the concrete.

Unlike reinforcing steel for cryogenic use, prestressing steel undergoes maximum tensile stress at ambient temperature during the tensioning process.

The notch ductility of the strand or wire is assumed to be acceptable since the action of cooling a stressed bar or wire with inherent crack-like defects caused by mechanical damage, or by the rolling process, does not induce the probability of brittle fracture. Local yielding of defects during the prestress operation at ambient temperature exceeds the strain for failure at low temperature.

Since the prestress relaxes as a result of prestrain and transfer losses, the critical strain for fracture cannot be achieved for a crack at low temperature. Thus toughness tests on prestressing steel strands or tendons at the design temperature are not necessary.

6.2.1 Tendons

Prestressing steel in the form of wire, strand or bar should conform to BS 4486:1980 or BS 5896:1980.

With a seven wire strand system, tests should be carried out to the satisfaction of the purchaser to demonstrate that centre wire slippage cannot occur at minimum service temperature.

6.2.2 Anchorages

Anchors for prestressing steel should be in accordance with BS 4447:1973, together with the following.

- a) The material from which the anchors are made should be suitable for the temperatures to which they are subject.

NOTE Cast iron is not regarded as suitable for use below -20°C .

- b) The suitability of the anchors for use at the intended temperatures should be demonstrated to the satisfaction of the purchaser by means of appropriate tests.

- c) An anchor system, such as wedge anchors for strand, which involves “pull-in” can result in indentations and thus should be employed only when the purchaser is satisfied, through additional tests, that the strength and toughness properties are not impaired and that the full load-elongation characteristic can be developed.

6.3 Reinforcing steels for concrete

6.3.1 Service at ambient temperatures

Steel bar, wire or mesh for reinforcing concrete which is designed for use at ambient temperature should be in accordance with BS 4449:1988, BS 4482:1985 or BS 4483:1985, as appropriate.

NOTE 1 These specifications include requirements for ductility (elongation) in the tensile test. Purchasers should utilize the available options to ensure that these requirements are met (see 6.3.2).

NOTE 2 Recommendations are also given in BS 8110-1.

6.3.2 Service at temperatures down to -20°C

For the design of reinforced concrete structure or elements where the design temperature during a normal operating or emergency condition does not fall below -20°C , reinforcing bar should conform to 6.3.1 as a minimum.

NOTE BS 4449, BS 4482 and BS 4483 do not include requirements for insuring against the risk of brittle fracture at low temperatures. However, reinforced concrete is a heterogeneous material and the reinforcing elements are separate items. Fracture of one element entails a redistribution of its load over adjacent elements without propagating its failure to those elements.

6.3.3 Service at temperatures below -20°C

For the design of reinforced concrete structure or elements where the design temperature during a normal operating or emergency condition falls below -20°C , steel reinforcement should conform to 6.3.1, and in addition one of the following alternatives should be adopted.

- a) Steel that meets the ductility and toughness recommended in 6.3.4.

NOTE 1 This may be carbon manganese steel, 9 % nickel steel or austenitic stainless steel.

- b) Reinforcing or prestressing steel with reduced allowable tensile stress.

NOTE 2 ANSI/NFPA 59A:1990[2] recommends a maximum allowable tensile stress for reinforcement for service temperatures down to -165°C . 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.

NOTE 3 Whilst the design temperature for the tank is deemed to be the product temperature, the design temperature for the embedded bar may be calculated assuming the temperature gradient that is present in the concrete component.

Table 1 lists the materials that should be used and their allowable tensile stresses in non-tensioned reinforcement for service at temperatures down to -165°C .

Table 1 — Allowable tensile stresses in non-tensioned reinforcement for service at temperatures down to -165°C

Reinforcing steel (conforming to BS 4449, BS 4482 or BS 4483)	
Diameter (d) mm	Allowable tensile stress N/mm ²
$d \leq 12$	82.7
$12 < d \leq 25$	68.9
$d > 25$	55.2
Prestressing steel (conforming to BS 4486 or BS 5896)	
Crack control applications	206.8
Other applications	55.2

6.3.4 Toughness and ductility

6.3.4.1 General

The ductility and toughness of carbon steel, carbon-manganese steel or ferritic alloy steel for reinforcing bars should be determined for applications where the design is for service below -20°C . Tests for ductility and toughness should be in accordance with 6.3.4.2.

NOTE Reinforcing steel undergoes a decrease in ductility with decreasing temperature, whilst experiencing an increase in both yield strength and ultimate tensile strength.

Where reinforcement is required for serviceability or loading conditions at above $-20\text{ }^{\circ}\text{C}$ only, and is not required to meet performance criteria when the concrete is subjected to the product temperature, the steel need not conform to the recommendations for toughness given in **6.3.4.1**. This would include reinforcement required for conditions such as shrinkage control, fire resistance, etc.

Fully-finished bar should be sampled from two production heats, from the maximum and minimum sample size for the order and from all strength grades to be used.

6.3.4.2 Testing

The manufacturing procedure for reinforcing bar should be approved by the purchaser and qualified in respect of toughness (see **6.3.4.3**). The supplier should not deviate from the qualified procedure without the prior approval of the purchaser. 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 $5\text{ }^{\circ}\text{C}$. The steel manufacturer should be given full details of the temperature operating range including test temperature.

Tensile tests in accordance with **C.1.2** to **C.1.4** of BS 4449:1988 and as stated below should be conducted on unnotched and notched bar specimens at the design temperature supplied by the purchaser. Tensile tests on notched bar specimens should be carried out and compared with the results on unnotched bar specimens to establish the notch sensitivity at the design temperature.

NOTE 1 The purchaser may require a temperature/notch sensitivity transition graph for which the notch sensitivity ratio can be determined at sufficient intervals to accurately plot the transition curve. The results should be submitted to the purchaser to demonstrate that the requirements of **6.3.4.2** have been met.

Test pieces cut from a length of reinforcing bar for testing in a cooling chamber should be between 500 mm and 1 000 mm, depending on diameter, but should be not less than $15 \times$ diameter. The test temperature should be the lowest design temperature that the reinforcement bar would be subjected to under abnormal loading conditions.

Tensile tests should be carried out at the design temperature to establish the strain during a tensile load test. For an unnotched bar the tensile test should establish the lower yield stress (for hot rolled bars) or the 0.2 % proof stress (for cold rolled bars). The percentage plastic elongation should be measured over a minimum gauge length (L_0) of 100 mm taken at a position at least $2d$ away from the point of subsequent fracture, where d is the diameter of the bar. (This is to avoid the possibility of measuring at a point at the onset of constriction of the test piece. See Figure 1 a).)

Each specimen should demonstrate a percentage plastic elongation of at least 3 %.

The notch sensitivity ratio (NSR) should be determined where:

$$\text{NSR} = \frac{\text{Tensile strength of notched bar}}{0.2\text{ \% proof stress of unnotched bar}} \text{ or } \frac{\text{Tensile strength of notched bar}}{\text{Lower yield stress of unnotched bar}}$$

The test specimens should be taken from adjacent positions in the same bar. $\text{NSR} \geq 1$ should be achieved for acceptable specimen 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 BS EN 10045-1:1990. 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 2). The percentage plastic elongation over a section with a minimum gauge length (L_0) of 100 mm separated from the notch by a minimum distance of $2d$, should be not less than 1 % [see Figure 1 b)].

NOTE 2 The above tests apply to straight unbent bars only.

Retests should be in accordance with clause **12** of BS 4449:1988. The loading rate on the specimen is limited such that the maximum stress increase rate is 180 N/mm^2 per minute in the elastic range and the maximum strain rate is 0.15 % per minute in the plastic range.

The percentage plastic elongation is the permanent percentile increase of the original gauge length (L_0) corresponding to tensile strength R_m .

6.3.4.3 Certification of reinforcing steel

For reinforcing steel the manufacturer should certify the following information:

- a) the steelmaking process;
- b) the chemical composition and range for C, Si, Mn, Ni, P, S, Nb, V, Ti, and Al;

- c) typical residual levels of Cr, Mo and Cu from recent production records;
- d) the billet reheating temperature;
- e) the finish rolling temperature;
- f) the controlled cooling conditions, if applicable.

6.4 Concrete

Prestressed concrete should conform to at least grade C40 of BS 5328-1:1991.

NOTE 1 The enhanced properties that are known to exist for concrete as a material of construction at low temperature should not be used in determining the material safety factors. However, the reduced expansion coefficient should be utilized. Recommendations for concrete and its constituents are given in BS 5328-1.

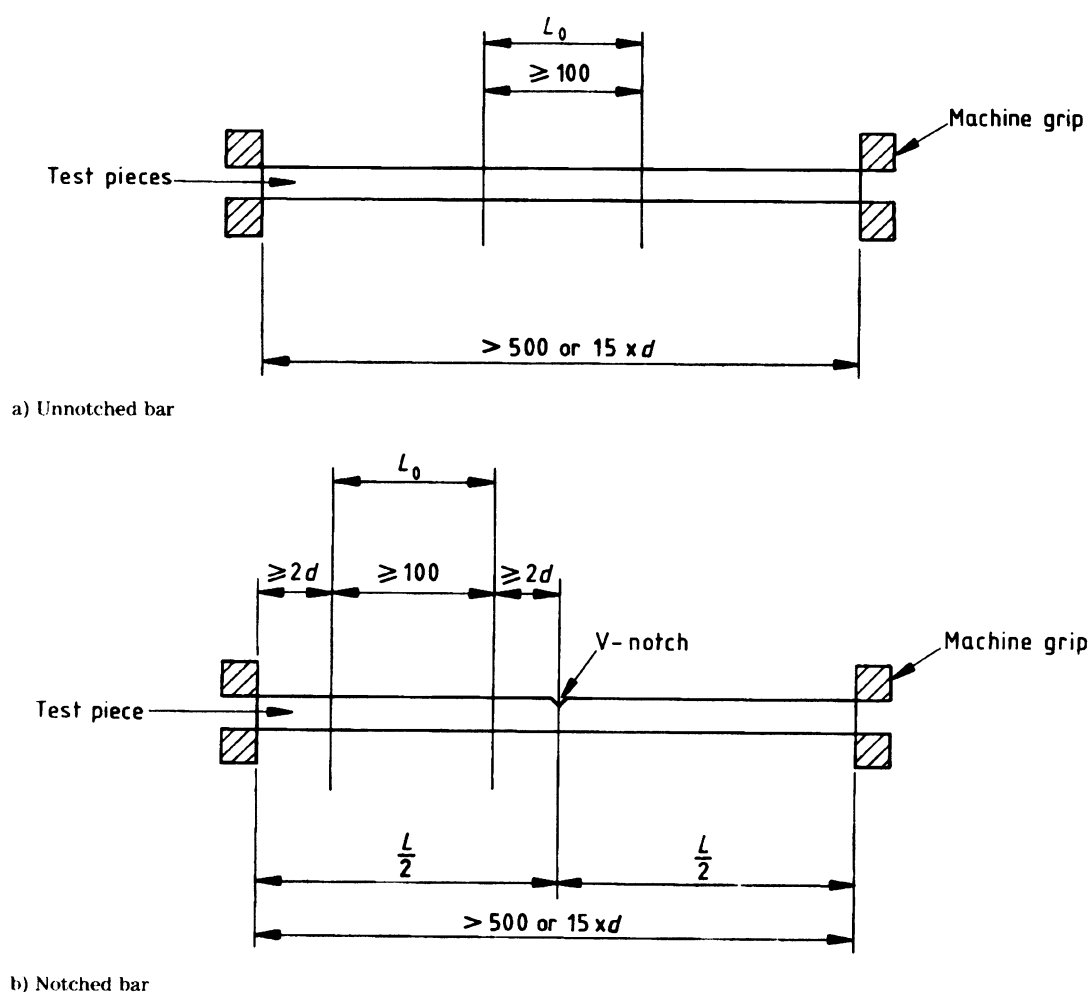
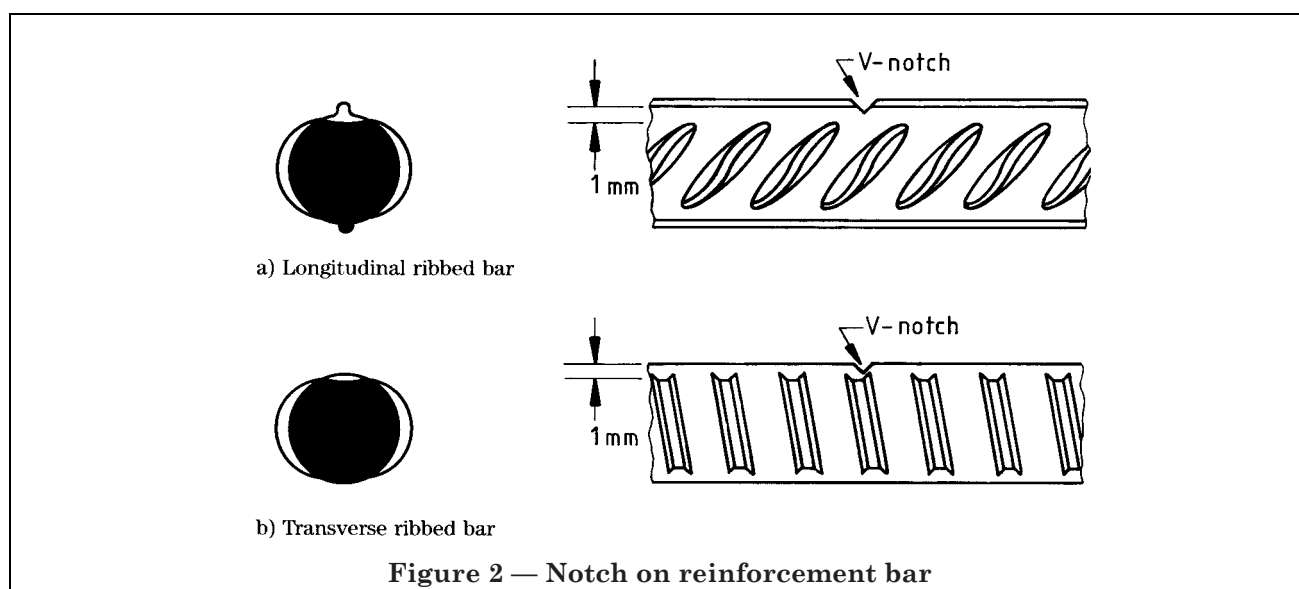


Figure 1 — Reinforcement bar specimen dimensions for testing at the design temperature in a cooling chamber



The concrete mix should be such that the concrete has acceptable properties with respect to the following:

- a) impermeability;
- b) freedom from cracks;
- c) fire resistance;
- d) behaviour at low temperature;
- e) durability;
- f) resistance to sulphate and chloride attack.

The mix should be designed to reduce the bulk water content such that internal ice formation, and hence internal cracking, is minimized. The water/cement ratio should not exceed 0.5. The use of plasticizers is permissible to obtain adequate workability.

NOTE 2 A low water/cement ratio 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.

The concrete mix may contain up to 5 % entrained air. Where the concrete can be subject to freeze/thaw cycles, tests should be carried out to demonstrate the suitability of the selected concrete mix.

Mixing, transportation, placing, curing and testing should be undertaken in accordance with BS 8110-1:1985 and BS 5328-1:1991, BS 5328-2:1991, BS 5328-3:1990 and BS 5328-4:1990.

NOTE 3 Ground granulated blast furnace slag (g.g.b.s.) or pulverised fuel ash (p.f.a.) may be used with conventional Portland cement.

NOTE 4 The use of g.g.b.s. or p.f.a. assists in reducing the heat of hydration of thick concrete sections and thus reducing the early thermal shrinkage. Natural uncrushed aggregates of high strength and low porosity are preferred to ensure maximum frost resistance.

6.5 Earth fill

The fill for the embankment should consist of selected material which is not sensitive to excessive consolidation.

Materials with a compacted density higher than $1\,750\text{ kg/m}^3$ and an angle of internal friction of at least 30° are preferred, e.g. sands and gravels.

NOTE 1 Granular soils placed and compacted in layers form high quality fill material. For compaction it is preferred that the material is not single-sized, but contains variation in grain size.

The permeability of the fill should be determined so that pore water pressure cannot develop during construction of the embankment.

NOTE 2 Significant settlement of an embankment may damage the slope protection and the roads located on the embankment. In addition it produces a downward loading on the wall due to friction between soil and the concrete of the wall.

Weak rock, such as mudstone, shales, marl and chalk, should not be used for heavily loaded embankments.

Soil with 35 % or more material by volume finer than 0.06 mm, organic soil or peat should not be used for embankment filling.

NOTE 3 Cohesive soils have a low permeability and this may result in very little consolidation during the construction of the embankment. It is essential that careful examination of the predicted consolidation settlement be made with cohesive soils. The installation of adequate drainage to prevent hydraulic pressure build up is recommended.

Material for the drainage layer should be selected to consist of rock or coarse fill with a silt and clay content limited to 4 % (V/V).

NOTE 4 At some locations the subsoil consists of impermeable material and a bottom drainage layer under the tank and the embankment may be required.

NOTE 5 Limiting the silt and clay content prevents clogging of the drainage system.