INTERNATIONAL STANDARD

ISO 28765

Second edition
2016-01-15

Vitreous and porcelain enamels — Design of bolted steel tanks for the storage or treatment of water or municipal or industrial effluents and sludges

Émaux vitrifiés — Conception de réservoirs en acier boulonnés pour le stockage ou le traitement des eaux ou des effluents d'eaux usées urbains ou industriels

Reference number
ISO 28765:2016(E)

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 107, *Metallic and other inorganic coatings*.

This second edition cancels and replaces the first edition (ISO 28765:2008), which has been technically revised.

Vitreous and porcelain enamels — Design of bolted steel tanks for the storage or treatment of water or municipal or industrial effluents and sludges

1 Scope

This International Standard establishes the requirements for the design and use of vitreous-enamel-coated bolted cylindrical steel tanks for the storage or treatment of water or municipal or industrial effluents and sludges.

It applies to the design of the tank and any associated roof and gives guidance on the requirements for the design of the foundation.

It applies where

a) the tank is cylindrical and is mounted on a load-bearing base substantially at or above ground level;

b) the product of the tank diameter in metres and the wall height in metres lies within the range 5 to 500;

c) the tank diameter does not exceed 100 m and the total wall height does not exceed 50 m;

d) the stored material has the characteristics of a liquid, exerting a negligible frictional force on the tank wall; the stored material may be undergoing treatment as part of a municipal or industrial effluent treatment process;

e) the internal pressure in the headspace above the liquid does not exceed 50 kPa and the internal partial vacuum above the liquid does not exceed 10 kPa;

f) the walls of the tank are vertical;

g) the floor of the tank is substantially flat at its intersection with the wall; the floor of the tank may have a rise or fall built in to allow complete emptying of the tank contents, the slope of which does not exceed 1:100;

h) there is negligible inertial and impact load due to tank filling;

i) the minimum thickness of the tank shell is 1,5 mm;

j) the material used for the manufacture of the steel sheets is carbon steel (tanks constructed of sheets made from aluminium or stainless steel are outside the scope of this International Standard);

k) the temperature of the tank wall during operation is within the range −50 °C to +100 °C under all operating conditions.

This International Standard also gives details of procedures to be followed during installation on site and for inspection and maintenance of the installed tank.

It does not apply to chemical-reaction vessels.

It does not cover resistance to fire.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 2178, *Non-magnetic coatings on magnetic substrates — Measurement of coating thickness — Magnetic method*

ISO 2746:2015, *Vitreous and porcelain enamels — High voltage test*

ISO 2859-1, *Sampling procedures for inspection by attributes — Part 1: Sampling schemes indexed by acceptance quality limit (AQL) for lot-by-lot inspection*

ISO 4532, *Vitreous and porcelain enamels — Determination of the resistance of enamelled articles to impact — Pistol test*

ISO 6370-2, *Vitreous and porcelain enamels — Determination of the resistance to abrasion — Part 2: Loss in mass after sub-surface abrasion*

ISO 8289:2000, *Vitreous and porcelain enamels — Low voltage test for detecting and locating defects*

ISO 15686-1, *Buildings and constructed assets — Service life planning — Part 1: General principles and framework*

ISO 28706-1:2008, *Vitreous and porcelain enamels — Determination of resistance to chemical corrosion — Part 1: Determination of resistance to chemical corrosion by acids at room temperature*

ISO 28706-2:2008, *Vitreous and porcelain enamels — Determination of resistance to chemical corrosion — Part 2: Determination of resistance to chemical corrosion by boiling acids, boiling neutral liquids and/or their vapours*

ISO 28706-3:2008, *Vitreous and porcelain enamels — Determination of resistance to chemical corrosion — Part 3: Determination of resistance to chemical corrosion by alkaline liquids using a hexagonal vessel*

ISO 28706-4:2008, *Vitreous and porcelain enamels — Determination of resistance to chemical corrosion — Part 4: Determination of resistance to chemical corrosion by alkaline liquids using a cylindrical vessel*

ISO 28763:2008, *Vitreous and porcelain enamels — Regenerative, enamelled and packed panels for air-gas and gas-gas heat exchangers — Specifications*

EN 15771, *Vitreous and porcelain enamels — Determination of surface scratch hardness according to the Mohs scale*

EN 1993-1-6, *Eurocode 3 — Design of steel structures — Part 1-6: Strength and Stability of Shell Structures*

EN 1993-4-1, *Eurocode 3 — Design of steel structures — Part 4-1: Silos*

EN 1993-4-2, *Eurocode 3 — Design of steel structures — Part 4-2: Tanks*

EN 1998-4, *Eurocode 8 — Design of structures for earthquake resistance — Part 4: Silos, tanks and pipelines*

EN 10209:2013, *Cold rolled low carbon steel flat products for vitreous enamelling — Technical delivery conditions*

ANSI/AWWA D 103, *Factory-Coated Bolted Steel Tanks for Water Storage*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
brief
working document which specifies at any point in time the relevant needs and aims of the project, the resources to be provided by the client, the details of the project and any applicable design requirements within which all subsequent briefing (when needed) and designing can take place

3.2
client
person or organization that requires a tank to be provided, altered or extended and is responsible for initiating and approving the brief

3.3
defect
break in the surface of the vitreous enamel

3.4
designer
person or organization responsible for stating the shape and specification of the component to be designed

3.5
design life
service life intended by the designer

3.6
discontinuity
weakness within the vitreous enamel coating that is detected by spark testing

3.7
enamel supplier
person or organization supplying materials for use by the vitreous enameller in the enamelling process

3.8
freeboard
distance between the top of the cylindrical-tank vertical shell wall and the surface of the contained liquid at the specified operating level

3.9
headspace pressure
pressure within a roofed tank above the stored liquid

3.10
inspection area
area inside a boundary 25 mm from any panel edge or hole and outside a boundary 25 mm from any opening or hole within the body of a panel

3.11
liquid
bulk substance that exerts substantially the same vertical and horizontal pressures and has no fixed shape

3.12
maintenance
combination of all technical and associated administrative actions during the service life to retain a tank or its parts in a state in which it can perform its required function

3.13
manufacturer
person or organization that manufactures the tank or parts of the tank

3.14
purchaser
person or organization purchasing the tank from the supplier

Note 1 to entry: The purchaser can also be the client.

3.15
rectification
return of a tank or its parts to an acceptable condition by the renewal, replacement or repair of worn, damaged or degraded parts

3.16
supplier
person or organization that supplies the tank or parts of the tank

3.17
service life
period of time after installation during which the tank or its parts meets or exceeds the performance requirements

3.18
tank
cylindrical, vertical shell for containing liquid, with or without a roof, which is constructed from vitreous-enamelled curved steel panels bolted together on the construction site and mounted on a base which may also form the floor of the container

3.19
vitreous enameller
person undertaking and controlling the process of preparing the steel sheets and applying the vitreous-enamel coating to the surfaces of the steel sheets

Note 1 to entry: The vitreous enameller will normally be the manufacturer.

3.20
vitreous enamel
substantially vitreous, or glassy inorganic silica coating bonded to metallic substrate by fusion at a temperature above 480 °C

Note 1 to entry: This coating is applied for protective functional and/or aesthetic purposes.

Note 2 to entry: This coating is produced by the proprietary formulation of silica glass, minerals and clays to produce a sprayable medium, dry or suspended in water on to the surface of the metallic substrate, and its subsequent fusion bonding.

4 Symbols and abbreviated terms

For the purposes of this document, the following symbols and abbreviated terms apply.

D tank diameter

E Young's modulus of elasticity

F_H static hoop force

g acceleration due to gravity

H depth of liquid at point under consideration, measured from the liquid surface at the maximum possible filling level

H_0 total vertical wall height

l length of shell between intermediate stiffeners

I_z second moment of area of a stiffener

p_n static liquid pressure at a specified depth

p_h headspace pressure

r tank radius

$q_{r,cr}$ critical external buckling pressure

q_{wmax} maximum stagnation pressure due to wind

w proportion of dissolved solids in sludge

t shell plate thickness

ν Poisson's ratio

γ partial load factor

ρ relative density of a liquid

σ stress

$\sigma_{z,cr}$ critical axial buckling resistance

cr (subscript) critical

ds (subscript) dissolved solids

h (subscript) headspace

max (subscript) maximum value

n (subscript) normal to the tank wall

s (subscript) sludge

w (subscript) wind

z (subscript) coincident with the central axis of a shell of revolution

φ (subscript) coincident with the radial axis of a shell of revolution

5 Units

The use of one of the following sets of consistent units is recommended:

— dimensions: m, mm

— unit weight: kN/m^3, N/mm^3

— forces and loads: kN, N

— line forces and line loads: kN/m, N/mm

— pressures and area-distributed actions: kPa, MPa

— unit mass: kg/m^3, kg/mm^3

— acceleration: km/s^2, m/s^2

— membrane-stress resultants: kN/m, N/mm

— bending-stress resultants: kNm/m, Nmm/mm

— stresses and elastic moduli: kPa, MPa (1 MPa = 1 N/mm^2)

6 Information and requirements to be agreed and documented

6.1 General

For the safe design and manufacture of the tank and associated parts, the specification shall be agreed between the contracting parties.

6.2 Information to be provided by the purchaser

The purchaser shall provide the supplier with a specification that shall include, but not be limited to, the following:

a) The specification of the stored liquid, that shall include, but not be limited to, the following:

   1) the name and/or a description of the liquid;

   2) the relative density;

   3) any relevant properties or characteristics particular to the liquid to be stored;

   4) the operating-temperature range.

b) The environmental conditions, that shall include, but not be limited to, the following:

   1) wind;

   2) seismic action;

   3) snow;

   4) ice;

   5) temperature ranges.

c) The use and planned dimensions of the tank, that shall include, but not be limited to, the following:

   1) the rates of fill and discharge;

   2) a summary describing the purpose of the tank and its method of operation;

   3) the net effects of the process on the tank or any of its components;

   4) the tank dimensions.

d) The planned location of all openings in the tank shell and roof.

e) Attached equipment:

   1) method of attachment;

   2) dead and live loads;

   3) connections.

f) The proximity of other tanks and buildings.

6.3 Information to be provided by the designer

The designer shall provide essential data concerning the design limitations of the tank, that shall include, but not be limited to, the following:

a) the name and a description of the stored liquid or liquids;

b) the range of the relative densities of the stored liquid or liquids;

c) the limits of the environmental criteria used in the design, including, where relevant, the design wind speed, the design operating-temperature range, the design snow load and the seismic zone and seismic coefficients;

d) the maximum access and superimposed loads used in the design;

e) a maintenance plan conforming to the requirements of ISO 15686-1;

f) guidance concerning change of use;

g) all relevant data assumed by the designer in the design process.

7 Applicable standards

All activities specified in this International Standard shall be carried out under an appropriate quality management system. A quality management system conforming to ISO 9001[2] will be deemed to satisfy this requirement.

The designer and client shall agree, through consultation, upon the applicable standards to be used for design purposes. Where provision is not made within this International Standard, other international or national standards may be specified.

The applicable standards agreed upon shall include, but not be limited to, standards providing details of parameters for the following design procedures:

a) hydrostatic loads;

b) wind loads;

c) seismic loads;

d) access loads;

e) snow loads;

f) rain loads;

g) load factors;

h) sheet strength calculations;

i) bolt strength calculations;

j) stability calculations;

k) foundation design.

8 Loads

8.1 General

All tanks and supporting structures shall be designed on a “limit state design” basis.

8.2 Contents

8.2.1 General

Loads due to the liquid shall be calculated considering:

a) the relative density of the specified range of liquids to be stored in the tank;

b) the geometry of the tank;

c) the maximum possible depth of the liquid in the tank.

If the liquid to be stored is sludge, and unless reliable or measured data are provided, the value of the relative density of the sludge, ρ_s, may be estimated by simple proportion using Formula (1):

$$\rho_s = 1 + w\left(\rho_{ds} - 1\right) \quad (1)$$

where ρ_{ds} is taken as 1,9 in the case of municipal sewage sludge.

8.2.2 Freeboard

The freeboard used for design purposes shall be as agreed between the client and the designer.

Where the tank is designed for seismic conditions, sufficient freeboard shall be provided to contain the sloshing wave determined in accordance with EN 1998-4. This shall take account of any equipment and structural members in the top of the tank.

8.2.3 Hydrostatic pressure

Determine the hydrostatic pressure, p_n, in kPa, acting on the tank shell at depth H using Formula (2):

$$p_n = H \times \rho \times g + p_h \quad (2)$$

8.2.4 Axial wall forces

The axial wall forces per unit shell width shall be determined taking account of the following:

a) the tank dead weight;

b) the imposed load;

c) the axial tension and compression due to the wind overturning moment;

d) the axial tension and compression due to seismic actions.

8.2.5 Filling and discharging

The method of filling and discharging the liquid can affect the load and shall be considered by the designer. These influences include, but are not limited to, the following:

a) the filling position — the inlet stream impinging on the tank wall;

b) completion of discharge — the risk of a hydrodynamic "water hammer" effect if the outlet is closed rapidly;

c) fatigue — the effect of the frequency of the filling and discharge cycles;

d) pressure and/or partial vacuum;

e) venting;

f) rapid changes in temperature.

8.3 Tank structure

The dead load shall be determined as the total weight of all structural components and permanent fittings.

8.4 Roof

The tank designer shall take account of all forces on the tank shell from the roof. These forces may include, but are not necessarily limited to, the following:

a) distributed in-plane and radial forces transmitted by structural roof members;

b) concentrated in-plane and radial forces resulting from structural features of the roof;

c) asymmetrical forces due to uneven distribution of imposed roof loads;

d) forces induced in the roof by differential settlement of the foundation.

8.5 Equipment loads

8.5.1 General

In the calculation of the total load on the tank, the designer shall take into account the effect of the attached equipment for both static and dynamic loads.

8.5.2 Static load

The static load of any equipment attached to the tank shall be determined as the weight of the equipment, including associated mounting fixtures and any liquid within the equipment, as advised by the purchaser.

8.5.3 Dynamic load

The dynamic forces caused by any equipment shall be determined, where applicable. They may include, but are not necessarily limited to, the following:

a) starting and operating forces from any rotating or moving piece of equipment mounted on or in the tank;

b) forces imposed on the tank or its attachments from installed process equipment (e.g. forces from restraining cables of floating aerators);

c) forces imposed on the tank or its attachments due to the operation of installed process equipment (e.g. forces on attached baffle plates due to forced movement of the tank contents).

8.6 Access

Where a roof is not designed to be accessible other than for normal cleaning and repair, the roof shall be designed using a uniform load of 0,6 kN/m^2.

Where the roof is designed to be accessible, it shall be designed using an imposed load appropriate for the intended usage taken from the applicable code but not less than1,5 kN/m^2.

Unless otherwise specified, loads transferred to the roof from walkways and platforms shall be assessed based on a uniform load appropriate for the intended usage taken from the applicable code, but not less than 3,0 kN/m^2 applied to the walkway or platform.

8.7 Environmental

8.7.1 General

Environmental loads shall be determined taking into account the design life of the tank.

8.7.2 Seismic action

Where relevant, seismic action shall be determined from the applicable standard.

The designer shall consider the following as a minimum requirement:

a) horizontal acceleration;

b) vertical acceleration;

c) sloshing of the contents;

d) the anchorage method;

e) dynamic ground response.

Guidance on the determination of seismic action can be found in the International Building Code, in ANSI/AWWA D 103 and in EN 1998-1 and EN 1998-4. When applying ANSI/AWWA D103 the latest version from which seismic data for the site location is available shall be used. When applying ANSI/AWWA D 103 in locations outside North America, zones determined from the 1997 Uniform Building Code[18] may be taken as equivalent.

8.7.3 Wind

The wind speed and pressure to be used for design purposes shall be determined from the applicable standard for the site location.

8.7.4 Snow

Where applicable, the load induced by snow shall be determined from the applicable standard for the site location.

8.7.5 Ice

Where applicable, the load induced by ice on the roof shall be determined from the applicable standard for the site location.

8.8 Ancillary items

The designer shall take account of the forces from ancillary items such as ladders, platforms, valves and machinery.

9 Design

9.1 General

The design of the tank shall be carried out using a "limit state design" approach. Design life assessment shall be based on ISO 15686-1.

9.2 Steel

9.2.1 Specification

The steel used shall have a specification, as agreed between the manufacturer, the designer and the steel supplier, having due regard to the requirements of the enamelling process.

NOTE Steels conforming to the requirements of EN 10111,[8] EN 10025-1[7] and EN 10149–1[9] (including grades DD 11, S235, S420 and S460), ASTM A 1011[17] and other standards can be used successfully for vitreous enamelling with appropriate pre-treatments.

9.2.2 Effects of the enamelling process

The designer shall take account of the effects of the vitreous-enamelling process on the strength properties of the steel and shall make details of such effects available to the client on request.

The effect of the enamelling process shall be assessed and monitored over a period of time, using a regular and documented test regime from which steel strength properties can be predicted with a 95 % confidence level.

Where regular and documented testing is not carried out, the yield and tensile strengths of the enamelled steel used for design purposes shall be reduced by 30 % from the guaranteed minimum strengths confirmed by the steel manufacturer.

9.3 Tank

9.3.1 Load factors

The load factors used in the design process shall be taken from Table 1.

Table 1 — Load factors

Basic load case	Maximum load factor γ
Dead load	1,4
Dead load acting with wind load, seismic load or imposed load	1,2
Liquid load	1,4
Imposed load	1,6
Imposed load acting with wind load	1,2
Wind load	1,4
Wind load acting with imposed load	1,2
Snow	1,4
Snow load in determining seismic loads	0,2
Snow load acting with seismic load	0,2
Seismic load [a]	1,2
Any load when the action is beneficial to the load case being considered	1,0

[a] Seismic actions need not be considered to act under test conditions.

9.3.2 Tank walls

9.3.2.1 General design

The walls of the tank shall be designed to resist the most demanding load combination.

The tank walls shall be designed to resist the forces and moments due to the connection to the foundation, including any nonlinear and stability effects.

For the purposes of this International Standard, wall friction forces due to the stored liquid are small and may safely be ignored.

9.3.2.2 Hoop force

The hoop force used in the determination of the shell plate thickness and vertical bolted-joint configuration shall take into account hydrostatic pressure and hydrodynamic pressure due to seismic action.

9.3.2.3 Static

Determine the hydrostatic hoop force per unit height, F_H, in kN·m^{-1}, at any level using Formula (3):

$$F_H = p_n \times \frac{D}{2} \quad (3)$$

9.3.2.4 Seismic

The design method employed by the designer shall take account of the following as a minimum requirement:

a) hydrodynamic hoop forces;

b) axial shell-compression and tension forces;

c) lateral and vertical anchorage forces;

The design of tanks for seismic resistance shall be in accordance with EN 1998-4 or Section 12 of ANSI/AWWA D 103.

Where the design is in accordance with ANSI/AWWA D 103, the loads determined shall be considered as characteristic loads, factored using load factors from Table 1 and compared to limit state capacities and buckling resistances determined in accordance with this International Standard.

9.3.2.5 Bolted joints

Bolts subject to shear forces shall be designed such that they are able to transmit forces between the shell plates which they connect. The bolt shall be proportioned such that the joint shear plane does not pass through any part of the thread or the thread run-out.

The vertical bolted joints between shell plates shall be designed to transfer the design hoop force between adjacent shell plates.

The vertical bolted joints shall be designed taking account of, as a minimum, the following:

a) the tensile stress on any net section through any structurally continuous sequence of bolts;

b) the bearing stress on the steel plates connected by the bolts;

c) the bearing stress on the bolts;

d) the shear stress in the bolts.

The hole bearing strength of the steel may be determined by testing or may be taken from the applicable standard for the steel being used. Where the bearing strength is determined by testing, details of the test method shall be made available to the client on request.

The bearing strength and shear strength of the bolts shall be taken from applicable standards and/or manufacturing bolt specifications that refer to applicable standards.

9.3.2.6 Axial wall forces

The designer shall consider the effects of axial wall forces on the axial buckling resistance of the tank shell. The effects of axial load combined with external wind pressure, roof live loads and any internal partial vacuum due to operational procedures or to the effects of wind-induced suction at roof vents shall also be considered.

The critical axial buckling resistance shall be determined by rigorous analysis. Critical buckling strengths determined in accordance with EN 1993-4-2 may be considered to satisfy this requirement.

Alternatively, the critical axial buckling resistance, $\sigma_{z,cr}$, in MPa, may be determined using Formula (4):

$$\sigma_{z,cr} = 0,3 \times E \times \frac{t}{r} \qquad (4)$$

Second-order effects can be present due to irregularities in the shell, particularly with large-diameter tanks, and the designer shall take account of these effects, where relevant.

9.3.2.7 External wind pressure

The designer shall consider the effects of external wind pressure on the following, with the tank in the empty condition:

a) external pressure buckling;

b) circumferential bending of the tank shell caused by wind pressure variation;

c) axial shell tension and compression;

d) the overturning resistance of the tank hold-down system.

The designer shall take account of the proximity of other tanks and buildings.

The resistance to external wind pressure buckling may be determined by rigorous analysis. Resistance to external wind pressure buckling determined in accordance with EN 1993-4-1 or EN 1993-1-6 may be taken to satisfy this requirement.

Alternatively, the critical external buckling pressure, $q_{r,cr}$, in MPa, may be determined using Formula (5):

$$q_{r,cr} = 0,8 \times \frac{Et^2}{lr} \sqrt[4]{\left(\frac{1}{1-\upsilon^2}\right)^3 \frac{t^2}{r^2}} \qquad (5)$$

Formula (5) shall be applied to the shell between the top shell stiffener and the first intermediate shell stiffener (or the base of the tank where no intermediate shell stiffeners are fitted), and to each successive portion between any subsequent intermediate shell stiffeners. Where the portion of shell under consideration is of non-uniform thickness, the mean thickness shall be used.

When comparing this resistance to the wind pressure acting on the tank, the wind pressure shall be taken as equal to the maximum wind pressure in the radial direction acting equally around the full 360° circumference of the tank.

The designer may consider a reduced wind speed when designing for test conditions.

The effect of the vitreous-enamel coating may be included in the calculation of shell stiffness in radial-buckling design provided the effect is demonstrated by rigorous analysis.

9.3.2.8 Top shell stiffener

For open-top tanks, the top shell stiffener shall be proportioned such as to provide sufficient support to prevent radial buckling of the tank shell. The top shell stiffener may be proportioned by rigorous analysis taking account of both ring buckling and bending effects. A top shell stiffener proportioned in accordance with EN 1993-4-1 may be deemed to satisfy this requirement.

Alternatively, the second moment of area of the top shell stiffener, I_z, in m^4, may be proportioned using Formula (6):

$$I_z = \frac{q_{w_{max}} H_0 r^3}{6E} \quad (6)$$

Additionally, for tanks fitted with a roof, the size of the top shell stiffener shall take account of the magnitude and distribution of the forces imposed by the roof structure and any fittings.

9.3.2.9 Intermediate shell stiffeners

Any intermediate shell stiffeners may be proportioned by rigorous analysis such as to provide sufficient support to prevent radial buckling of the ring or group of rings of the tank shell over which it can be shown to be effective. Intermediate shell stiffeners proportioned in accordance with EN 1993-4-1 may be deemed to satisfy this provision.

Alternatively, the second moment of area of the intermediate shell stiffeners, I_z, in m^4, may be proportioned using Formula (7):

$$I_z = \frac{q_{w_{max}} l r^3}{3E} \quad (7)$$

where l is the distance between intermediate stiffener rings or between the lowest intermediate stiffener ring and the bottom of the tank.

9.3.2.10 Thermal

The design of the tank structure shall consider the consequences of thermal effects (displacement, strain, curvatures, stresses, forces and moments) due to the temperature difference between the stored liquid and the tank structure and/or between the external environment and the tank structure. The designer shall also consider the effects of ice formation on the surface of the stored liquid.

9.3.2.11 Internal pressure

For roofed tanks, the designer shall take account of the effects of internal pressure on the design and thickness of the tank walls.

9.3.2.12 Internal vacuum

For open-top tanks, the designer shall take account of the partial vacuum generated inside of the tank due to the effects of wind and shall combine these with the external wind pressure when designing the tank shell.

For roofed tanks, the designer shall take into account any internal vacuum resulting from the operating conditions, and from the action of wind pressure and suction on any roof vents, and shall combine these with the external wind pressure when designing the tank shell. These effects shall be considered with the tank in the empty condition.

9.3.3 Tank roof

As a minimum requirement, the designer shall take account of the following:

a) the dead load;

b) the live load — snow, access, wind, rain, seismic;

c) internal pressure and vacuum;

d) roof openings;

e) compression and tension in any structural stiffening member fitted to the tank at its interface with the roof.

9.3.4 Attachment of walls to floor

The connection between the tank walls and the tank base shall be designed to transmit the vertical forces in the tank walls and the horizontal shear forces and bending moments due to liquid loads, wind loads, seismic loads and internal pressure to the foundation.

9.3.5 Tank floor

9.3.5.1 Concrete

Unless a surface coating or treatment is to be applied, the concrete used to form the floor of the tank shall be waterproof.

9.3.5.2 Vitreous-enamelled steel plates

All vitreous-enamelled floor plates shall be fully bolted along all seams. The number of bolts shall be sufficient to ensure a waterproof seal in conjunction with a suitable sealant material.

NOTE A suitable seal is one which adequately protects the bolted joint and is flexible, while curing chemically to form a homogenous barrier.

9.3.5.3 Foundation

Where the supplier is responsible for complete design and supply of the tank, including the foundation, the client shall provide the supplier with site soil survey data as necessary.

The manufacturer shall furnish plans for the connection of the tank to the foundation, including shear loads, where critical, if requested by the purchaser, and containing all relevant details to allow the foundation to be designed for the specific site conditions. The foundation shall be designed in accordance with the applicable standard. An exclusion zone for reinforcing bars may be specified in the foundation at the location where the tank and foundation are connected in order to facilitate the installation of the hold-down system or to avoid the risk of establishing a galvanic cell.

As a minimum requirement, the designer shall take into account the following:

a) the dead load;

b) the live load;

c) the tank/foundation interaction forces (moments and shear forces), including any nonlinear and stability effects;

d) the expansion of the tank shell under load;

e) environmental loads (wind and seismic);

f) thermal expansion;

g) the soil conditions at the proposed construction site and the potential for differential settlement.

9.3.6 Ancillary items

Where ancillary items are required for access or safety, the client and the supplier shall agree upon the applicable standard.

9.3.7 Cathodic protection

Where routine inspection and maintenance is impractical due to access limitations, commercial factors or ongoing process requirements, then it may be beneficial for the client to consider the installation of a suitable cathodic-protection system to provide additional security. The cathodic-protection system shall be designed and installed by an engineer registered with a national or international organization (e.g. NACE).

The designer of the cathodic-protection system shall take into account the following:

a) the electrical resistivity of the stored liquid;

b) the area of exposed steel surface;

c) the electrical connectivity between the tank contents, the tank structure, the foundation concrete, the foundation-reinforcing steel and submerged ancillary steel items;

d) the current density required to inhibit corrosion when selecting the material for a sacrificial anode.

NOTE Sacrificial-anode-type cathodic-protection systems provide a relatively simple, low-cost, manageable and easy to install solution.

9.4 Openings

9.4.1 Access manway

For roofed tanks, at least one low-level access manway shall be provided. The location shall be agreed between the client and the supplier.

For open-top tanks, the positions for any required access manways shall be agreed between the client and the supplier.

Any removable cover shall be attached with a hinge or other supporting device.

9.4.2 Pipe connections

The size of pipe connections and their point of attachment to the tank shall be agreed between the client and the supplier.

9.4.3 Overflows

The tank shall be equipped with an overflow of a capacity and at a location to be agreed between the client and the supplier. The overflow shall be designed such that it does not produce any negative pressure inside the tank and roof structure and such that there can be no contamination of the inlet water by back-syphoning.

A suitable air gap may be necessary between the overflow and the inlet connection. This shall be the subject of agreement between the purchaser and the supplier.

9.4.4 Reinforcement of manways and pipe connections in the tank shell

All openings having a minimum dimension greater than 100 mm, cut into any section of the tank, that are subject to hydrostatic pressure shall be reinforced.

The minimum net cross-sectional area of the reinforcement, allowing for any bolt holes, shall not be less than the product of the maximum vertical dimension of the hole cut into the tank shell and the minimum design shell thickness. In addition to the saddle(s), only those elements of the reinforcement neck that lie within a distance of four times the thickness of the neck from the shell plate may be considered as a part of the reinforcing area.

9.4.5 Connections in the roof

9.4.5.1 General

The size of the roof opening and pipe connections and the points of attachment of the pipe connections shall be specified and agreed between the client and supplier.

Access openings wider than 250 mm shall be provided with a suitable safety device to prevent unauthorized access.

9.4.5.2 Venting

Where the roof forms a gas-tight seal with the tank, the roof shall be fitted with a vent or pressure/vacuum relief device of a capacity to prevent the pressure/vacuum exceeding the design limits for the tank shell or roof under the most extreme normal operating conditions.

With closed tanks, the design of the venting shall take into account all relevant operational conditions, including, but not limited to, the following.

a) adding and extracting liquids;

b) the build-up of internal pressure or vacuum from environmental or process factors;

c) screening to prevent the ingress of birds, animals or insects;

d) the symmetry of the air flow from the tank plan area.

Vents fitted with screens require regular inspection and cleaning in order to maintain their efficiency.

9.5 Effects of accidents

9.5.1 Risk assessment

The client shall provide all relevant history of the potential risk involved in dealing with the product to allow due account to be taken by the designer of the tank and supporting structure. The designer shall consider at least the following where applicable.

9.5.2 Explosions

The potential damage from an explosion shall be limited or avoided by taking appropriate measures, such as:

a) incorporating sufficient pressure-relief features;

b) incorporating suppression measures;

c) details of maintenance and cleaning routines;

d) safe selection of electronic equipment to avoid possible ignition sources.

9.5.3 Uncontrolled fluctuation in input stream characteristics

The client shall make the designer aware of any history of significant accidental fluctuations of input stream characteristics from the agreed specification in respect of temperature, chemical nature, flow rate and any other characteristic likely to affect the tank design.

10 Vitreous-enamel coating

10.1 Vitreous enamel

The vitreous enameller shall specify the requirements for all raw materials to be used in the vitreous-enamelling process and ensure that they will produce a coating that will meet the minimum quality requirements listed in Tables 2 and 3 when processed through the intended vitreous-enamelling plant. The vitreous enameller or the enamel supplier shall carry out tests and record the conformity of the enamelled materials in accordance with Table 2 and shall make certified copies of these records available for subsequent inspection.

All raw materials used in the production of vitreous-enamel-coated panels shall meet the specification as described in this clause and shall be agreed between the manufacturer and the material supplier, having due regard to the requirements of the enamelling process.

10.2 Coating

The vitreous-enamel coating used on any panel surface coming into contact with the stored liquid shall meet the minimum quality requirements shown in Table 2, in which dark shading has been used to fill irrelevant/inapplicable boxes and the black blobs indicate which requirements are to be met.

The client shall satisfy himself that the vitreous-enamel coating is suitable for the intended purpose.

Prior to coating, the steel shall be free of all oil, lubricants and other contaminants.

10.3 Vitreous-enamel quality

10.3.1 Preparation and test frequency

Test specimens of vitreous-enamelled steel shall be prepared and tested at least at the minimum inspection frequency specified in Table 2 to ensure that the enamel meets the relevant quality requirements set out in Table 2.

10.3.2 Inspection

10.3.2.1 Sampling procedure

Inspection shall be carried out using a sampling procedure conforming to the requirements of ISO 2859-1. Test apparatus shall be calibrated using calibration instruments having an accuracy of ± 1 %. Test apparatus shall have valid calibration records.

10.3.2.2 Finished panels

10.3.2.2.1 General

Tests shall be carried out within the inspection area of the finished panel and shall meet the specification as set out in Table 3, in which dark shading has been used to fill irrelevant/inapplicable boxes and the black blobs indicate which tests are to be carried out. For the purposes of these tests, any panel surface coming into contact with the stored liquid shall be treated as an inside surface.

Following the enamelling process, finished panels shall be inspected by the manufacturer on both the inside and the outside surface under good daylight or equivalent artificial lighting.

10.3.2.2.2 Inside surface

The inside panel surface shall be inspected for defects as shown in Table 3.

10.3.2.2.3 Outside surface

The outside panel surface shall be inspected for defects as shown in Table 3.

10.3.2.3 Enamel thickness

The thickness of the enamel shall be measured using an approved instrument having a measurement range of 0 µm to 500 µm. The thickness of the enamel on any panel shall be maintained within the range shown in Table 3. Panels having an enamel thickness outside these limits shall be rejected.

10.3.2.4 Enamel colour

The colour of the enamelled-sheet surfaces and the colour tolerance limits shall be agreed by the interested parties. Conformity shall be determined using a colour comparator.

10.3.3 On-site rectification

The manufacturer shall provide a procedure for on-site rectification and on-site touch-up of damaged coatings.