Singapore Standard SS EN 1993-4-2:2011

Eurocode 3: Design of steel structures
– Part 4-2 : Tanks

AMENDMENT NO. 1

April 2020

1. Page 6, Modifications to Foreword

In the section "National Annex for EN 1993-4-2", in the 2nd paragraph, *delete* "– 4.3.1 (6) " and "– 4.3.1 (8)".

2. Page 8, Modifications to 1.1 Scope

(a) *Replace* Paragraph (1) with the following:

(1) Part 4-2 of Eurocode 3 provides principles and application rules for the structural design of vertical cylindrical, conical and pedestal above ground steel tanks for the storage of liquid products with the following characteristics:

a) tanks with capacity greater than 100 m^3 (100 000 1);

b) tanks that have significant fabrication or assembly on site;

c) shop-fabricated tanks with conical bottoms, supported on skirts or columns;

d) tanks with characteristic internal pressures above the liquid surface not more negative than -0,1 bar and not greater than 0,5 bar[1)];

e) design metal temperatures limited to the ranges:

1) tanks constructed using structural steel grades, -50°C < *T* < +300°C;

2) tanks constructed using austenitic stainless steels, -165°C < *T* < +300°C;

3) tanks constructed with special steel grades that have defined yield strengths up to higher temperatures, -165°C < *T* < the maximum defined temperature for the grade;

4) tanks susceptible to failure by fatigue, *T* < 150°C;

f) in cylindrical ground-supported tanks, the maximum design liquid level not higher than the top of the cylindrical shell.

(b) *Replace* Paragraph (8) with the following:

(8) This Part 4-2 does not cover:

— tanks of rectangular planform;

— tanks with capacity below 100 m^3;

— tanks exposed to fire (refer to EN 1993-1-2);

— tanks with dished ends and diameter less than 5 m;

— cylindrical tanks with an aspect ratio of height to diameter greater than 3.

3. Page 8, Modification to 1.2 Normative references

*Replace "*EN 1990", "EN 1993 Part 1.6, Part 1.10 and Part 4.1:" with "EN 1990:2002", "EN 1993 Part 1.6: 2007, Part 1.10:2005 and Part 4.1 : 2007" respectively.

4. Page 10, Modifications to 1.5 Terms and definitions

Delete Entry 1.5.3 and *renumber* the following numbered entries accordingly.

Replace "1.5.1, 1.5.5, 1.5.6, 1.5.8, 1.5.9, 1.5.13, 1.5.15, 1.5.17, 1.5.18, 1.5.20 and 1.5.23" with the following:

1.5.1 **shell**. A structure formed from a curved thin plate. In the tank construction industry, this term is also taken to have the special meaning of the vertical wall of a cylindrical tank, see 1.5.9.

1.5.5 (new numbering 1.5.4) **circumferential direction.** The horizontal tangent to the tank wall at any point. It varies around the tank, lies in the horizontal plane and is tangential to the tank wall.

1.5.6 (new numbering 1.5.5) **middle surface.** This term is used to refer to the stress-free middle surface when a shell is subject to pure bending in any direction.

1.5.8 (new numbering 1.5.7) **tank.** A tank is a vessel for storing liquid products. In this standard it is assumed to be circular in plan.

1.5.9 (new numbering 1.5.8) **shell.** The term shell is often used in the tank industry to refer to the vertical wall of a cylindrical tank. This usage is slightly confusing when compared with the general definition (see EN 1993-1-6) given in 1.5.1, it is quite widely used, so it is also used in this standard where appropriate. Where any confusion may arise, the term cylindrical wall is used instead.

1.5.13 (new numbering 1.5.12) **junction**. A junction is the point at which any two or more shell segments meet. It can include a stiffener or not: the point of attachment of a ring stiffener to the shell may be treated as a junction.

1.5.15 (new numbering 1.5.14) **shell-roof junction**. The shell-roof junction, alternatively known as the top angle or eaves junction, is the junction between the vertical wall and the roof.

1.5.17 (new numbering 1.5.16) **rib.** A rib is a local member that provides a primary load carrying path for loads causing bending down the meridian of a shell, representing a generator of the shell of revolution. It is used to distribute transverse loads on the structure by bending action.

1.5.18 (new numbering 1.5.17) **ring stiffener.** A ring stiffener is a local stiffening member that passes around the circumference of the structure at a given point on the meridian. It is assumed to have no stiffness in the meridional plane of the structure. It is provided to increase the stability or to introduce local loads, not as a primary load-carrying element.

1.5.20 (new numbering 1.5.19) **ring girder or ring beam**. A ring girder or ring beam is a circumferential stiffener which has bending stiffness and strength in the plane of the circular section of a shell and also normal to that plane. It is a primary load-carrying element, used to distribute local loads into the shell.

1.5.23 (new numbering 1.5.22) **catch basin.** An external tank structure to contain fluid that may escape by leakage or accident from the primary tank. This type of structure is usually used where the primary tank contains toxic or dangerous fluids. A catch basin also effectively reduces the requirement for an extensive area of fluid containment around the tank.

5. Page 14, Modification to 1.7.2 Conventions for global tank structure axis system for rectangular tanks

Delete the entire Subclause 1.7.2 including Figure 1.2, and renumber Subclauses 1.7.3 and 1.7.4 as 1.7.2 and 1.7.3.

6. Page 15, Modifications to 1.7.3 (new numbering 1.7.2), Conventions for structural element axes in both circular and rectangular tanks

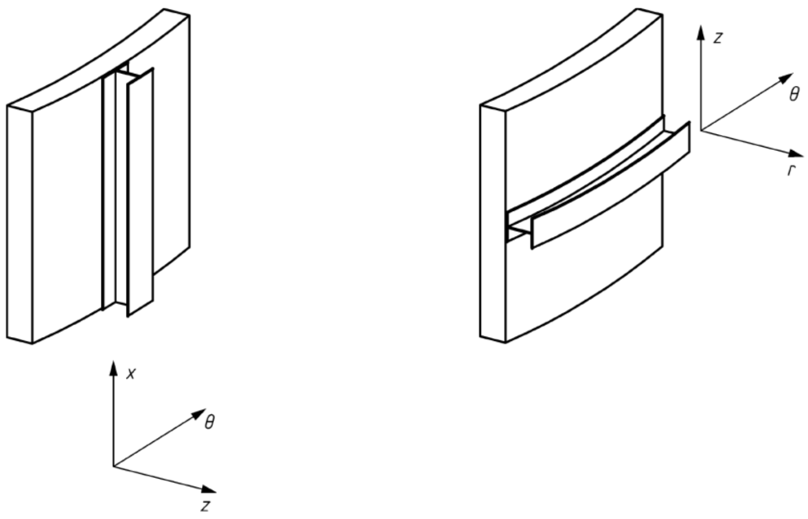
Replace the entire subclause with the following:

1.7.2 Conventions for structural element axes in circular tanks

(1) The convention for structural elements attached to the tank wall (see Figure 1.2) is different for meridional and circumferential members.

(2) The convention for meridional straight structural elements (see Figure 1.2a) attached to the tank wall is:

Meridional coordinate for cylinder, hopper and roof attachment	x
Strong bending axis (parallel to flanges)	y
Weak bending axis (perpendicular to flanges)	z



a) Meridional stiffener **b) Circumferential stiffener**

Figure 1.2 – Local coordinate systems for meridional and circumferential stiffeners.

(3) The convention for circumferential curved structural elements (see Figure 1.2b)

attached to a shell wall is:

Circumferential coordinate axis (curved)	θ
Radial axis	r
Vertical axis	z

7. Page 17, Modification to 1.7.4 (new numbering 1.7.3) Conventions for stress resultants for circular tanks and rectangular tanks

Replace the entire 1.7.4 with the following:

1.7.4 Conventions for stress resultants for circular tanks

(1) The convention used for subscripts indicating membrane forces is:

“The subscript derives from the direction in which direct stress is induced by the force” for direct stress resultants. For membrane shears and twisting moments, the sign convention is shown in Figure 1.3.

Membrane stress resultants, see Figure 1.3:

n_x	meridional membrane stress resultant
n_θ	circumferential membrane stress resultant in shells
n_{xy} or $n_{x\theta}$	membrane shear stress resultant

Membrane stresses:

σ_{mx}	meridional membrane stress
$\sigma_{m\theta}$	circumferential membrane stress in shells
σ_{mxy} or $\tau_{mx\theta}$	membrane shear stress

(2) The convention used for subscripts indicating moments is:

“The subscript derives from the direction in which direct stress is induced by the moment”. For twisting moments, the sign convention is shown in Figure 1.3.

NOTE: This plate and shell convention is at variance with beam and column conventions used in Eurocode 3: Parts 1.1 and 1.3. Care needs to be exercised when using them in conjunction with these provisions.

Bending stress resultants, see Figure 1.3:

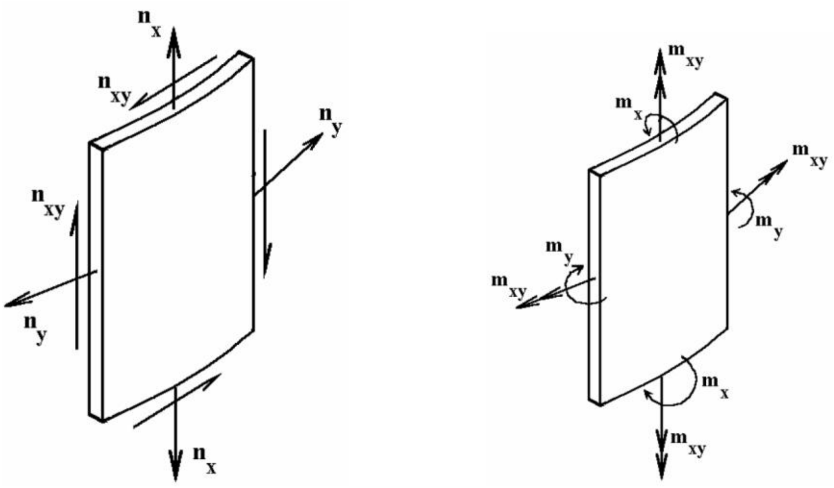
m_x	meridional bending moment per unit width
m_θ	circumferential bending moment per unit width in shells
m_{xy} or $m_{x\theta}$	twisting shear moment per unit width

Bending stresses:

σ_{bx}	meridional bending stress
$\sigma_{b\theta}$	circumferential bending stress in shells
τ_{bxy} or $\tau_{bx\theta}$	twisting shear stress

Inner and outer surface stresses:

σ_{six}, σ_{sox}	meridional inner, outer surface stress
$\sigma_{si\theta}$, $\sigma_{so\theta}$	circumferential inner, outer surface stress in shells



a) Membrane stress resultants **b) Bending stress resultants**

Figure 1.3 – Stress resultants in the tank wall (shells and boxes)

8. Page 19, Modifications to 2.2 Reliability differentiation

Replace Paragraphs (1) to (4)P with the following:

(1) For reliability differentiation, see EN 1990.

NOTE The National Annex may define the Consequence Classes for tanks as a function of the location, type of stored fluid and loading, the structural form, size and operational aspects.

(2) Different levels of rigour should be used in the design of tank structures, depending on the Consequence Class chosen, the structural arrangement and the susceptibility to different failure modes.

(3) For this standard, three Consequence Classes are used, with requirements which produce designs with essentially equal risk in the design assessment and considering the expense and procedures necessary to reduce the risk of failure for different structures: Consequence Classes 1, 2 and 3.

NOTE The National Annex may choose appropriate values for the boundaries between the classes. Table 2.1 gives recommended values for the classification based on the size, structural form and stored contents into Consequence Classes when all other parameters result in medium consequences, see EN 1990:2002, B.3.1.

(4) The classification of flat-bottomed tanks that rest on the ground is based on the dimension U, which is related to the potential energy of the stored fluid.

$$U = \sqrt{DH} \qquad \text{…(2.1)}$$

where D is the tank diameter and H is the maximum depth of stored fluid (see Figure 2.1a).

Table 2.1 a) – Recommended Consequence Class definition depending on contents, size and structural form

Consequence Class	Design Situations
Consequence Class 3	a) Tanks storing liquids or liquefied gases with toxic or explosive potential; b) All flat-bottomed tanks used to store fluids at or near the top of a building; c) All pedestal tanks with centroidal height $H_g \geq H_{g\alpha}$ (see Fig. 2.1b); d) Ground-supported water tanks with parameter U in the range $U > U_{3\alpha}$; e) Ground-supported tanks storing water-polluting liquids with parameter U in the range $U > U_{3b}$; f) Ground-supported tanks storing flammable liquids with parameter U in the range $U > U_{3c}$; Emergency loadings should be taken into account for these structures where necessary, see A.2.14.
Consequence Class 2	a) All pedestal tanks not in Consequence Class 3; b) Ground-supported water tanks with parameter U in the range $U2\alpha < U \leq U3\alpha$; c) Ground-supported tanks storing water-polluting liquids with parameter U in the range $U2b < U \leq U3b$; d) Ground-supported tanks storing flammable liquids with parameter U in the range $U2c < U < U3c$.
Consequence Class 1	All other tanks within the scope of this standard.

NOTE 1 – The recommended values for class boundaries are as follows:

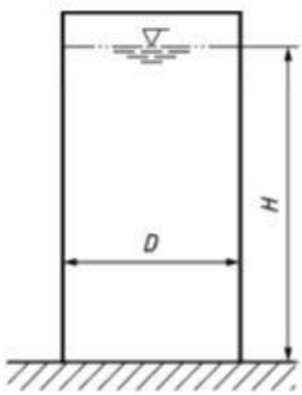
Table 2.1 b) – Recommended values for class boundaries

Class Boundary	Recommended Value
$H_{g\alpha}$	30 m
$U_{3\alpha}$	27 m
U_{3b}	24 m
U_{3c}	15 m
$U_{2\alpha}$	18 m
U_{2b}	15 m
U_{2c}	10 m

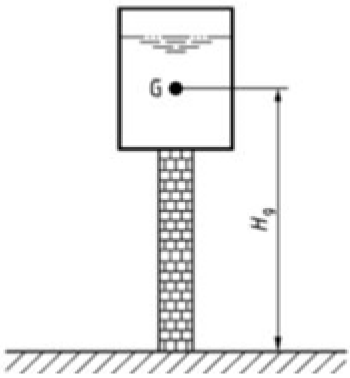
NOTE 2 For the classification by Action Assessment Classes, see EN 1991-4.

(5) A higher Consequence Class than that required may always be adopted.

(6)P The choice of relevant Consequence Class shall be agreed between the designer, the client and the relevant authority.



a) Basic geometry of ground-supported tank



b) Centroidal height of fluid in a pedestal tank

Figure 2.1 – Dimensions defined or Consequence Classes

9. Page 20, Modifications to 2.7 Modelling of the tank for determining action effects

Replace Paragraphs (2) and (3) with the following:

(2) The specific requirements for structural analysis in relation to serviceability set out in 5.5 and 6.5 should be used for the relevant structural segments.

(3) The specific requirements for structural analysis in relation to ultimate limit states set out in 5.3 and 6.3 (and in more detail in EN 1993-1-6) should be applied.

10. Page 24, Modifications to 3.5.1 General

Replace Paragraphs (1) and (2) with the following:

(1) The toughness requirements should be determined for the reference temperature T_{ed} according to EN 1993-1-10.

(2) The minimum design metal temperature T_{MDMT} should be determined according to 3.5.2. The temperature T_{MDMT} should be used in place of (T_{md} + ΔT_r) in 2.2(5) of EN 1993-1-10:2005.

11. Page 24, Modifications to 3.5.2 Minimum design metal temperature

Replace Paragraphs (1) and (2) with the following:

(1) The minimum design metal temperature T_{MDMT} should be the lowest of the minimum temperature of the contents or those classified in Table 3.1.

(2) The lowest one day mean ambient temperature T_{LODMAT} should be taken as the lowest recorded temperature averaged over any 24 h period. Where insufficiently complete records are available, this average temperature may be taken as the mean of the maximum and minimum temperatures or an equivalent value.

Table 3.1 – Minimum design metal temperature T_{MDMT} based on T_{LODMAT}

Lowest one day mean ambient temperature T_{LODMAT}	Minimum design metal temperature T_{MDMT}	
	10 years data	30 years data
- 10°C ≤ T_{LODMAT}	T_{LODMAT} +5°C	T_{LODMAT} +10°C
- 25°C ≤ T_{LODMAT} ≤ -10°C	T_{LODMAT}	T_{LODMAT} +5°C
T_{LODMAT} ≤ - 25°C	T_{LODMAT} -5°C	T_{LODMAT}

12. Page 25, Modification to 4.1.3 Effects on corrosion

Replace the entire subclause with the following:

4.1.3 Allowance for corrosion

(1) The responsibility for corrosion losses in a tank lies entirely with the client, owner or end user.

(2) The life expectancy of the tank and its intended usage should be agreed between the client, the engineer and the relevant authority.

(3) The wall thickness reduction to account for the effects of corrosion should be agreed between the designer, the client and the relevant authority, taking account of the intended use, any internal lining, the nature of the liquid to be stored and the life expectancy of the tank.

Reference may be made to EN 12285-1:2003, Annex B, if applicable.

(4) Wall thickness losses and damage to internal structures due to corrosion should be considered in the design calculations.

(5) The extent of corrosion loss depends upon the stored liquid, the type of steel, the heat treatment, the life expectancy of the tank and any measures taken to protect the construction against corrosion.

(6) Where a suitable protection system, as approved by the relevant authority where appropriate, is provided to guarantee protection against corrosion (e.g. glass lining of the internal surface, cathodic protection etc.), no corrosion loss provision need be considered.

(7) Consideration should also be given to corrosion by the atmosphere above the level of the stored fluid, especially if it may contain steam.

NOTE The National Annex may choose appropriate values for corrosion losses for particular liquid in contact with defined tank wall materials for a defined life expectancy.

(8) Appropriate provision should be made for periodic inspection of the tank wall thickness, with reference made to its original design thickness at every level.

13. Page 26, Modification to 4.2.2.1 General

Replace Paragraph (3) with the following:

(3) Irrespective of the Consequence Class chosen, the simplified design described in Clause 7 may be used if the conditions listed there are met.

14. Page 27, Deletion of 4.3 Analysis of the box structure of a rectangular tank

Delete Subclause 4.3 and *renumber* Subclause 4.4 as Subclause 4.3.

15. Page 29, Modification to 5.3 Resistance of the tank shell wall

Replace the title with “Resistance of the structural segments of the tank”.

Add the following Paragraphs (4) and (5) after Paragraph (3):

(4) The design of conical hoppers should satisfy the requirements of EN 1993-4-1.

(5) The design of transition junctions at the bottom of a cylindrical wall and supporting ring girders should satisfy the requirements of EN 1993-4-1.

16. Page 31, Modification to 5.4.6.3 Design of shell man holes and shell nozzles of large size for LS1

In Paragraph (6), r*eplace* “t is the shell plate thickness” with the following:

t is the shell plate thickness required to resist only internal pressure from the stored fluid and overpressure

17. Pg. 33, Modification to 5.4.7 Anchorage of the tank

Replace Paragraph (3) with the following:

(3) Where a uniformly supported anchored tank is subject to horizontal loads (e.g. wind) the anchorage forces should be calculated according to either linear shell bending theory or semi-membrane theory. They should not be calculated using beam theory.

It should be noted that these forces are locally much higher than those found using beam theory. See Paragraph (3) in 5.4.7 of EN 1993-4-1:2007.

18. Page 34, Deletion of 6 Design of conical hoppers

Delete the entire Clause 6 and renumber Clause 7 as Clause 6 and its subclauses accordingly. (*Renumber* also Formula (7.1) as Formula (6.1).)

19. Page 34, Modification to 7.1.2 (newly numbered as 6.1.2), Roof design

In Paragraph (2), replace "7.3 to 7.5" with "6.3 to 6.5".

20. Page 35, Modification to 7.3 (newly numbered as 6.3), Resistance of circular roofs

In Paragraph (1), *replace* "7.4" with "6.4".

21. Page 35, Modification to 7.4.3 (newly numbered as 6.4.3), Roof to shell junction (eaves junction)

In Paragraph (2), *replace* "11.1" with "7.1" and "11.2.5" with "7.2.5".

22. Page 36, Deletion of 8 Design of transition junctions at the bottom of the shell and supporting ring girders

Delete entire Clause 8.

23. Page 37, Deletion of Clause 9, Design of rectangular and planar-sided tanks

Delete entire Clause 9.

24. Page 38, Modification to Clause 10, Requirements on fabrication, execution and erection with relation to design

Delete entire Clause 10.

25. Page 39, Modification to Clause 11 (newly numbered as Clause 7), Simplified design

Renumber Clause 11 as Clause 7 and renumber accordingly the subclauses, tables, figures and formulae contained in it.

26. Page 40, Modification to 11.2.1 (newly numbered as 7.2.1), Unstiffened roof shell butt welded or with double lap weld

In Paragraph (2), *replace* "section 7" with "Clause 6".

27. Page 47, Modifications to 11.3.2 (newly numbered as 7.3.2) Stiffening rings

After Paragraph (14), *insert* the following new Paragraphs (15) and (16):

(15) A rational method should be used to determine the required size of one or more intermediate ring stiffeners.

(16) It may be useful to apply the provisions of EN 1993-1-6:2007, 8.7 using the LBA-MNA method to obtain the elastic critical mode and critical buckling pressure and to estimate the plastic reference pressure for any proposed ring stiffening design.

NOTE It may be noted that a value of R_{cr} greater than 2 will typically fulfil the requirements of a more complete analysis.

28. Page 53, Modification to A.1 General

Replace Paragraph (2) with the following:

(2) The partial factors on actions according to 2.9.2.1.