EESTI STANDARD EVS-EN 1993-4-2:2007+NA:2010

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

Eurokoodeks 3: Teraskonstruktsioonide projekteerimine
Osa 4-2: Vedelikumahutid

EESTI STANDARDIKESKUS
ESTONIAN CENTRE FOR STANDARDISATION

EESTI STANDARDI EESSÕNA	NATIONAL FOREWORD
See Eesti standard EVS-EN 1993-4-2:2007+NA:2010 sisaldab Euroopa standardi EN 1993-4-2:2007 ja selle paranduse AC.2009 ingliskeelset teksti ning Eesti rahvuslikku lisa NA:2010.	This Estonian Standard EVS-EN 1993-4-2:2007+NA:2010 consists of the English text of the European Standard EN 1993-4-2:2007 including its corrigendum AC:2009 and the Estonian National Annex NA:2010.
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EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

EN 1993-4-2

February 2007

ICS 23.020.01; 91.010.30; 91.080.10

Supersedes ENV 1993-4-2:1999

English Version

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

Eurocode 3 - Calcul des structures en acier - Partie 4-2: Réservoirs

Eurocode 3 - Bemessung und Konstruktion von Stahlbauten - Teil 4-2: Silos,Tankbauwerke und Rohrleitungen - Tankbauwerke

This European Standard was approved by CEN on 12 June 2006.

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EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
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Foreword

This European Standard EN 1993-4-2, Eurocode 3: Design of steel structures: “Design of Steel Structures – Part 4-2: Tanks”, has been prepared by Technical Committee CEN/TC250 « Structural Eurocodes », the Secretariat of which is held by BSI. CEN/TC250 is responsible for all Structural Eurocodes.

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of an identical text or by endorsement, at the latest by August 2007, and conflicting National Standards shall be withdrawn at latest by March 2010.

This Eurocode supersedes ENV1993-4-2: 1999.

According to the CEN-CENELEC Internal Regulations, the National Standard Organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, 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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Background of the Eurocode programme

In 1975, the Commission of the European Community decided on an action programme in the field of construction, based on article 95 of the Treaty. The objective of the programme was the elimination of technical obstacles to trade and the harmonisation of technical specifications.

Within this action programme, the Commission took the initiative to establish a set of harmonised technical rules for the design of construction works which, in a first stage, would serve as an alternative to the national rules in force in the Member States and, ultimately, would replace them.

For fifteen years, the Commission, with the help of a Steering Committee with Representatives of Member States, conducted the development of the Eurocodes programme, which led to the first generation of European codes in the 1980’s.

In 1989, the Commission and the Member States of the EU and EFTA decided, on the basis of an agreement[1)] between the Commission and CEN, to transfer the preparation and the publication of the Eurocodes to the CEN through a series of Mandates, in order to provide them with a future status of European Standard (EN). This links de facto the Eurocodes with the provisions of all the Council’s Directives and/or Commission’s Decisions dealing with European standards (e.g. the Council Directive 89/106/EEC on construction products - CPD - and Council Directives 93/37/EEC, 92/50/EEC and 89/440/EEC on public works and services and equivalent EFTA Directives initiated in pursuit of setting up the internal market).

The Structural Eurocode programme comprises the following standards generally consisting of a number of Parts:

EN1990	Eurocode 0: Basis of structural design
EN1991	Eurocode 1: Actions on structures
EN1992	Eurocode 2: Design of concrete structures

1) Agreement between the Commission of the European Communities and the European Committee for Standardisation (CEN) concerning the work on EUROCODES for the design of building and civil engineering works (BC/CEN/03/89).

EN1993	Eurocode 3: Design of steel structures
EN1994	Eurocode 4: Design of composite steel and concrete structures
EN1995	Eurocode 5: Design of timber structures
EN1996	Eurocode 6: Design of masonry structures
EN1997	Eurocode 7: Geotechnical design
EN1998	Eurocode 8: Design of structures for earthquake resistance
EN1999	Eurocode 9: Design of aluminium structures

Eurocode standards recognise the responsibility of regulatory authorities in each Member State and have safeguarded their right to determine values related to regulatory safety matters at national level where these continue to vary from State to State.

Status and field of application of Eurocodes

The Member States of the EU and EFTA recognise that EUROCODES serve as reference documents for the following purposes:

- as a means to prove compliance of building and civil engineering works with the essential requirements of Council Directive 89/106/EEC, particularly Essential Requirement N°1 - Mechanical resistance and stability - and Essential Requirement N°2 - Safety in case of fire ;
- as a basis for specifying contracts for construction works and related engineering services ;
- as a framework for drawing up harmonised technical specifications for construction products (ENs and ETAs)

The Eurocodes, as far as they concern the construction works themselves, have a direct relationship with the Interpretative Documents[2)] referred to in Article 12 of the CPD, although they are of a different nature from harmonised product standards[3)]. Therefore, technical aspects arising from the Eurocodes work need to be adequately considered by CEN Technical Committees and/or EOTA Working Groups working on product standards with a view to achieving full compatibility of these technical specifications with the Eurocodes.

The Eurocode standards provide common structural design rules for everyday use for the design of whole structures and component products of both a traditional and an innovative nature. Unusual forms of construction or design conditions are not specifically covered and additional expert consideration will be required by the designer in such cases.

National Standards implementing Eurocodes

The National Standards implementing Eurocodes will comprise the full text of the Eurocode (including any annexes), as published by CEN, which may be preceded by a National title page and National foreword, and may be followed by a National Annex.

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2) According to Art. 3.3 of the CPD, the essential requirements (ERs) shall be given concrete form in interpretative documents for the creation of the necessary links between the essential requirements and the mandates for harmonised ENs and ETAGs/ETAs.

3) According to Art. 12 of the CPD the interpretative documents shall :

a) give concrete form to the essential requirements by harmonising the terminology and the technical bases and indicating classes or levels for each requirement where necessary ;

b) indicate methods of correlating these classes or levels of requirement with the technical specifications, e.g. methods of calculation and of proof, technical rules for project design, etc. ;

c) serve as a reference for the establishment of harmonised standards and guidelines for European technical approvals.

The Eurocodes, de facto, play a similar role in the field of the ER 1 and a part of ER 2.

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The National Annex may only contain information on those parameters which are left open in the Eurocode for national choice, known as Nationally Determined Parameters, to be used for the design of buildings and civil engineering works to be constructed in the country concerned, i.e. :

- values and/or classes where alternatives are given in the Eurocode,
- values to be used where a symbol only is given in the Eurocode,
- country specific data (geographical, climatic, etc), e.g. snow map,
- the procedure to be used where alternative procedures are given in the Eurocode.

It may also contain:

- decisions on the application of informative annexes,
- references to non-contradictory complementary information to assist the user to apply the Eurocode.

Links between Eurocodes and harmonised technical specifications (ENs and ETAs) for products

There is a need for consistency between the harmonised technical specifications for construction products and the technical rules for works[4)]. Furthermore, all the information accompanying the CE Marking of the construction products which refer to Eurocodes should clearly mention which Nationally Determined Parameters have been taken into account.

Additional information specific to EN1993-4-2

EN 1993-4-2 gives design guidance for the structural design of tanks.

EN 1993-4-2 gives design rules that supplement the generic rules in the many parts of EN 1993-1.

EN 1993-4-2 is intended for clients, designers, contractors and relevant authorities.

EN 1993-4-2 is intended to be used in conjunction with EN 1990, with EN 1991-4, with the other Parts of EN 1991, with EN 1993-1-6 and EN 1993-4-1, with the other Parts of EN 1993, with EN 1992 and with the other Parts of EN 1994 to EN 1999 relevant to the design of tanks. Matters that are already covered in those documents are not repeated.

Numerical values for partial factors and other reliability parameters are recommended as basic values that provide an acceptable level of reliability. They have been selected assuming that an appropriate level of workmanship and quality management applies.

Safety factors for 'product type' tanks (factory production) can be specified by the appropriate authorities. When applied to 'product type' tanks, the factors in 2.9 are for guidance purposes only. They are provided to show the likely levels needed to achieve consistent reliability with other designs.

National Annex for EN1993-4-2

This standard gives alternative procedures, values and recommendations for classes with notes indicating where national choices may have to be made. Therefore the National Standard implementing EN 1993-4-2 should have a National Annex containing all Nationally Determined Parameters to be used for the design of buildings and civil engineering works to be constructed in the relevant country.

National choice is allowed in EN 1993-4-2 through:

– 2.2 (1)
– 2.2 (3)

4) see Art.3.3 and Art.12 of the CPD, as well as clauses 4.2, 4.3.1, 4.3.2 and 5.2 of ID 1.

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- 2.9.2.1 (1)P
- 2.9.2.1 (2)P
- 2.9.2.1 (3)P
- 2.9.2.2 (3) P
- 2.9.3 (2)
- 3.3 (3)
- 4.1.4 (3)
- 4.3.1 (6)
- 4.3.1 (8)

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1 General

1.1 Scope

(1) Part 4.2 of Eurocode 3 provides principles and application rules for the structural design of vertical cylindrical above ground steel tanks for the storage of liquid products with the following characteristics

a) characteristic internal pressures above the liquid level not less than −100mbar and not more than 500mbar [1];

b) design metal temperature in the range of −50ºC to +300ºC. For tanks constructed using austenitic stainless steels, the design metal temperature may be in the range of −165ºC to +300ºC. For fatigue loaded tanks, the temperature should be limited to T < 150ºC;

c) maximum design liquid level not higher than the top of the cylindrical shell.

(2) This Part 4.2 is concerned only with the requirements for resistance and stability of steel tanks. Other design requirements are covered by EN 14015 for ambient temperature tanks and by EN 14620 for cryogenic tanks, and by EN 1090 for fabrication and erection considerations. These other requirements include foundations and settlement, fabrication, erection and testing, functional performance, and details like man-holes, flanges, and filling devices.

(3) Provisions concerning the special requirements of seismic design are provided in EN 1998-4 (Eurocode 8 Part 4 “Design of structures for earthquake resistance: Silos, tanks and pipelines”), which complements the provisions of Eurocode 3 specifically for this purpose.

(4) The design of a supporting structure for a tank is dealt with in EN 1993-1-1.

(5) The design of an aluminium roof structure on a steel tank is dealt with in EN 1999-1-5.

(6) Foundations in reinforced concrete for steel tanks are dealt with in EN 1992 and EN 1997.

(7) Numerical values of the specific actions on steel tanks to be taken into account in the design are given in EN 1991-4 "Actions on Silos and Tanks". Additional provisions for tank actions are given in annex A to this Part 4.2 of Eurocode 3.

(8) This Part 4.2 does not cover:

– floating roofs and floating covers;

– resistance to fire (refer to EN 1993-1-2).

(9) The circular planform tanks covered by this standard are restricted to axisymmetric structures, though they can be subject to unsymmetrical actions, and can be unsymmetrically supported.

1.2 Normative references

This European Standard incorporates, by dated and undated reference, provisions from other standards. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to, or revisions of, any of these publications apply to the European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies.

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[1] All pressures are in mbar gauge unless otherwise specified

EN 1090-2 *Execution of steel and aluminium structures – Technical requirements for steel structures*

EN 1990 *Eurocode: Basis of structural design;*

EN 1991 *Eurocode 1: Actions on structures;*

Part 1.1: *Actions on Structures - Densities, self weight and imposed loads for buildings;*

Part 1.2: *Actions on structures - Actions on structures exposed to fire;*

Part 1.3: *Actions on structures - Snow loads;*

Part 1.4: *Actions on structures - Wind loads;*

Part 4: *Actions on silos and tanks;*

EN 1992 *Eurocode 2 : Design of concrete structures ;*

EN 1993 *Eurocode 3: Design of steel structures;*

Part 1.1: *General rules and rules for buildings;*

Part 1.3: *General rules - Supplementary rules for cold formed members and sheeting;*

Part 1.4: *General rules – Supplementary rules for stainless steels;*

Part 1.6: *General rules - Supplementary rules for the strength and stability of shell structures;*

Part 1.7: *General rules - Supplementary rules for planar plated structures loaded transversely;*

Part 1.10: *Material toughness and through thickness properties;*

Part 4.1: *Silos;*

EN 1997 *Eurocode 7: Geotechnical design;*

EN 1998 *Eurocode 8: Design of structures for earthquake resistance;*

Part 4: *Silos, tanks and pipelines;*

EN 1999 *Eurocode 9: Design of aluminium structures;*

Part 1.5: *Shell structures;*

EN 10025 *Hot rolled products of non-alloy structural steels – technical delivery conditions*;

EN 10028 *Flat products made of steel for pressure purposes;*

EN 10088 *Stainless steels*

EN 10149 *Specification for hot-rolled flat products made of high yield strength steels for cold forming.*

Part 1: *General delivery conditions*

Part 2: *Delivery conditions for thermomechanically rolled steels*

Part 3: *Delivery conditions for normalized or normalized rolled steels*

EN 13084 *Freestanding industrial chimneys*

Part 7: *Product specification of cylindrical steel fabrications for use in single wall steel chimneys and steel liners*

EN 14015 *Specification for the design and manufacture of site built, vertical, cylindrical, flat bottomed, above ground, welded, metallic tanks for the storage of liquids at ambient temperatures*

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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 –5°C and –165°C;*
ISO 1000	*SI Units;*
ISO 3898	*Bases for design of structures – Notation – General symbols;*
ISO 8930	*General principles on reliability for structures - List of equivalent terms.*

1.3 Assumptions

(1) In addition to the general assumptions of EN 1990 the following assumption applies:

- fabrication and erection complies with EN 1090, EN 14015 and 14620 as appropriate

1.4 Distinction between principles and application rules

(1) See 1.4 in EN 1990.

1.5 Terms and definitions

(1) The terms that are defined in 1.5 in EN 1990 for common use in the Structural Eurocodes and the definitions given in ISO 8930 apply to this Part 4.2 of EN 1993, unless otherwise stated, but for the purposes of this Part 4.2 the following supplementary definitions are given:

1.5.1 shell. A structure formed from a curved thin plate. This term also has a special meaning for tanks: see 1.7.2.

1.5.2 axisymmetric shell. A shell structure whose geometry is defined by rotation of a meridional line about a central axis.

1.5.3 box. A structure formed from an assembly of flat plates into a three-dimensional enclosed form. For the purposes of this standard, the box has dimensions that are generally comparable in all directions.

1.5.4 meridional direction. The tangent to the tank wall at any point in a plane that passes through the axis of the tank. It varies according to the structural element being considered.

1.5.5 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 irrespective of whether the tank is circular or rectangular in plan.

1.5.6 middle surface. This term is used to refer to both the stress-free middle surface when a shell is in pure bending and the middle plane of a flat plate that forms part of a box.

1.5.7 separation of stiffeners. The centre to centre distance between the longitudinal axes of two adjacent parallel stiffeners.

Supplementary to Part 1 of EN 1993 (and Part 4 of EN 1991), for the purposes of this Part 4.2, the following terminology applies:

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1.5.8 tank. A tank is a vessel for storing liquid products. In this standard it is assumed to be prismatic with a vertical axis (with the exception of the tank bottom and roof parts).

1.5.9 shell. The shell is the cylindrical wall of the tank of circular planform. Although this usage is slightly confusing when it is compared to the definition given in 1.4.1, it is so widely used with the two meanings that both have been retained here. Where any confusion can arise, the alternative term "cylindrical wall" is used.

1.5.10 tank wall. The metal plate elements forming the vertical walls, roof or a hopper bottom are referred to as the tank wall. This term is not restricted to the vertical walls.

1.5.11 course. The cylindrical wall of the tank is formed making horizontal joints between a series of short cylindrical sections, each of which is formed by making vertical joints between individual curved plates. A short cylinder without horizontal joints is termed a course.

1.5.12 hopper. A hopper is a converging section towards the bottom of a tank. It is used to channel fluids towards a gravity discharge outlet (usually when they contain suspended solids).

1.5.13 junction. A junction is the point at which any two or more shell segments or flat plate elements meet. It can include a stiffener or not: the point of attachment of a ring stiffener to the shell or box may be treated as a junction.

1.5.14 transition junction. The transition junction is the junction between the vertical wall and a hopper. The junction can be at the base of the vertical wall or part way down it.

1.5.15 shell-roof junction. The shell-roof junction is the junction between the vertical wall and the roof. It is sometimes referred to as the eaves junction, though this usage is more common for solids storages.

1.5.16 stringer stiffener. A stringer stiffener is a local stiffening member that follows the meridian of a shell, representing a generator of the shell of revolution. It is provided to increase the stability, or to assist with the introduction of local loads or to carry axial loads. It is not intended to provide a primary load carrying capacity for bending due to transverse loads.

1.5.17 rib. A rib is a local member that provides a primary load carrying path for loads causing bending down the meridian of a shell or flat plate, representing a generator of the shell of revolution or a vertical stiffener on a box. It is used to distribute transverse loads on the structure by bending action.

1.5.18 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. In a shell of revolution it is circular, but in rectangular structures is takes the rectangular form of the plan section.

1.5.19 base ring. A base ring is a structural member that passes around the circumference of the structure at the base and is required to ensure that the assumed boundary conditions are achieved in practice.

1.5.20 ring girder or ring beam. A ring girder or ring beam is a circumferential stiffener which has bending stiffness and strength both in the plane of the circular section of a shell or the plan section of a rectangular structure and also normal to that plane. It is a primary load-carrying element, used to distribute local loads into the shell or box structure.

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1.5.21 continuously supported. A continuously supported tank is one in which all positions around the circumference are supported in an identical manner. Minor departures from this condition (e.g. a small opening) need not affect the applicability of the definition.

1.5.22 discrete support. A discrete support is a position in which a tank is supported using a local bracket or column, giving a limited number of narrow supports around the tank circumference.

1.5.23 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 used where the primary tank contains toxic or dangerous fluids.

1.6 Symbols used in Part 4.2 of Eurocode 3

The symbols used are based on ISO 3898:1987.

1.6.1 Roman upper case letters

A area of cross-section
A_1, A_2 area of top, bottom flange of roof centre ring
D diameter of tank
E Young's modulus
H height of part of shell wall to liquid surface; maximum design liquid height
H_0 height of the tank shell
I second moment of area of cross-section
K coefficient for buckling design
L height of shell segment or stiffener shear length
M bending moment in structural member
N axial force in structural member
N_f minimum number of load cycles relevant for fatigue
P vertical load on roof rafter
R radius of curvature of shell which is not cylindrical
T temperature
W elastic section modulus; weight

1.6.2 Roman lower case letters

a side length of a rectangular opening in the shell
b side length of a rectangular opening in the shell; width of a plate element in a cross-section
c_p coefficient for wind pressure loading
d diameter of manhole or nozzle
e distance of outer fibre of beam to beam axis
f_y design yield strength of steel
f_u ultimate strength of steel
h rise of roof (height of apex of a dome roof above the plane of its junction to the tank shell)
height of each course in tank shell
j joint efficiency factor; stress concentration factor; count of shell wall courses
l height of shell over which a buckle may form
m bending moment per unit width
n membrane stress resultant
number of rafters in circular tank roof
p distributed loading (not necessarily normal to wall)
p_n pressure normal to tank wall (outward)
r radius of middle surface of cylindrical wall of tank
t wall thickness

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w minimum width of base ring annular plate
x radial coordinate for a tank roof
y local vertical coordinate for a tank roof; replacement factor used in design of reinforced openings
z global axial coordinate
coordinate along the vertical axis of an axisymmetric tank (shell of revolution)

1.6.3 Greek letters

α slope of roof
β inclination of tank bottom to vertical; = π/n where n is the number of rafters
γ_F partial factor for actions
γ_M partial factor for resistance
δ deflection
Δ change in a variable
ν Poisson's ratio
θ circumferential coordinate around shell
σ direct stress
τ shear stress

1.6.4 Subscripts

E value of stress or displacement (arising from design actions)
F at half span; action
a annular
d design value
f fatigue
i inside; inward directed; counting variable
k roof centre ring
k characteristic value
m mean value
min minimum allowed value
n nominal; normal to the wall
o outside; outward directed
p pressure
r radial; ring
R resistance
s at support
s shell wall
x meridional; radial; axial
y circumferential; transverse; yield
0 reference value
1 upper
2 lower
θ circumferential (shells of revolution)

1.7 Sign conventions

1.7.1 Conventions for global tank structure axis system for circular tanks

(1) The sign convention given here is for the complete tank structure, and recognises that the tank is not a structural member. Care with coordinate systems is required to ensure that local coordinates associated with members attached to the shell wall and loadings given in local coordinate directions but defined by a global coordinate are not confused.

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(2) In general, the convention for the global tank structure axis system is in cylindrical coordinates (see figure 1.1) as follows:

Coordinate system

Coordinate along the central axis of a shell of revolution	z
Radial coordinate	r
Circumferential coordinate	θ

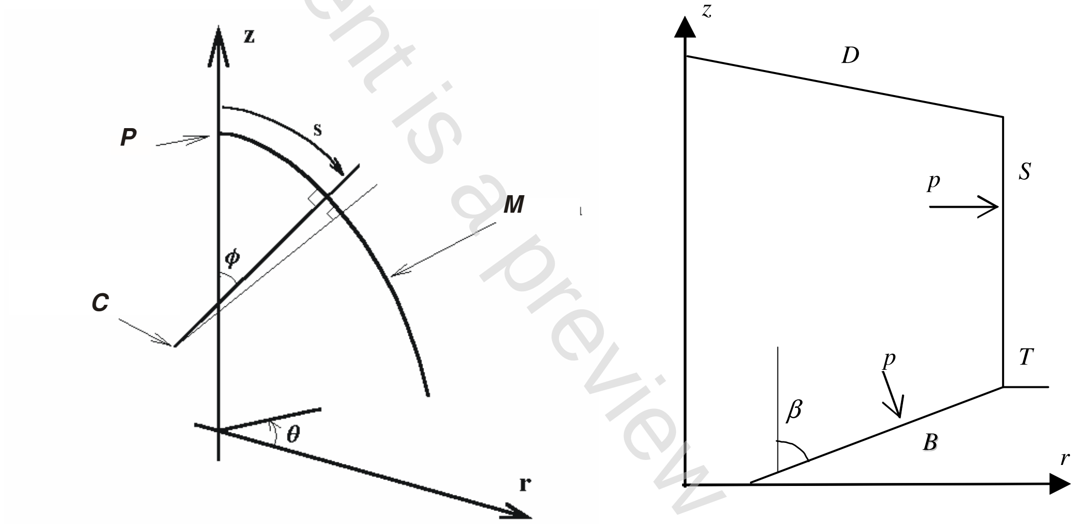
(3) The convention for positive directions is:

Outward direction positive (internal pressure positive, outward displacements positive)

Tensile stresses positive (except in buckling equations where compression is positive)

(4) The convention for distributed actions on the tank wall surface is:

Pressure normal to shell (outward pressure) p_n



P= pole; *M*= shell meridian; *C*= Instantaneous centre of meridional curvature

a) 3D sketch with general axisymmetric shell coordinate system

D= roof; *S*= shell; *B*= bottom; *T*= transition

b) coordinates and loading: vertical section

Figure 1.1: Coordinate systems for a circular tank

1.7.2 Conventions for global tank structure axis system for rectangular tanks

(1) The sign convention given here is for the complete tank structure, and recognises that the tank is not a structural member. Care with coordinate systems is required to ensure that local coordinates associated with members attached to the box wall and loadings given in local coordinate directions but defined by a global coordinate are not confused.

(2) In general, the convention for the global tank structure axis system is in Cartesian coordinates x, y, z, where the vertical direction is taken as z (see figure 1.2).

(3) The convention for positive directions is:

Outward direction positive (internal pressure positive, outward displacements positive)

Tensile stresses positive (except in buckling equations where compression is positive)

Shear stresses: see 1.8.4

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