
Simplified design of prestressed concrete tanks for potable water

*Conception simplifiée du réservoir pour l'eau potable en béton pré-
armé*

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Contents

	Page
Foreword	vi
Introduction	vii
1 Scope	1
2 Normative references	1
3 Terms and definitions	1
4 Symbols	4
5 Design principles	12
6 Load	13
6.1 General.....	13
6.2 Deadweight.....	13
6.3 Imposed load.....	13
6.4 Hydrostatic water pressure.....	14
6.5 Prestress.....	14
6.5.1 General.....	14
6.5.2 Prestressing force immediately after prestressing.....	14
6.5.3 Effective prestressing force.....	18
6.5.4 Indeterminate forces due to prestress.....	19
6.6 Creep and drying shrinkage of concrete.....	19
6.7 Effect of temperature.....	19
6.8 Seismic action.....	20
6.9 Wind load.....	20
6.10 Snow load.....	20
6.11 Earth pressure.....	21
6.12 Uplift pressure force.....	22
6.13 Other loads.....	22
7 Structural analysis	22
7.1 Calculation of member force.....	22
7.2 Concrete.....	22
7.2.1 Strength.....	22
7.2.2 Modulus of elasticity.....	23
7.2.3 Poisson's ratio.....	23
7.2.4 Drying shrinkage.....	23
7.2.5 Creep.....	23
7.3 Steel.....	25
7.3.1 Strength.....	25
7.3.2 Modulus of elasticity.....	26
7.3.3 Relaxation.....	26
7.4 Calculation of tensile reinforcement.....	26
8 Stress limit	27
8.1 General.....	27
8.2 Stress limit of reinforced concrete members.....	28
8.2.1 Stress limit of concrete.....	28
8.2.2 Stress limit of reinforcement.....	28
8.3 Stress limit of prestressed concrete members.....	28
8.3.1 Stress limit of concrete.....	28
8.3.2 Tensile stress limit of prestressing steel.....	29
8.3.3 Stress limit of reinforcement.....	29
8.3.4 Augmentation of tensile stress limit of concrete.....	29
9 Verification of safety against earthquake	29
9.1 Principles of seismic design.....	29
9.1.1 General.....	29

9.1.2	Ground motion levels.....	29
9.1.3	Levels of earthquake resistance	29
9.1.4	Effects of earthquake.....	30
9.1.5	Seismic design procedure.....	30
9.2	Input earthquake motion.....	30
9.2.1	Seismic design method.....	30
9.2.2	Design seismic coefficients for the seismic coefficient method for Level 1 ground motion.....	31
9.2.3	Design seismic coefficients for the seismic coefficient method for Level 2 ground motion.....	32
9.2.4	Seismic input for design by dynamic analysis.....	33
9.3	Verification of structural safety.....	33
9.3.1	Effects of earthquake.....	33
9.3.2	Combination of loads.....	37
9.3.3	Calculation of member forces.....	38
9.3.4	Safety verification.....	47
9.4	Investigation for foundation.....	54
10	General structural details.....	54
10.1	Prestressing steel.....	54
10.1.1	Clear distance.....	54
10.1.2	Concrete cover.....	55
10.1.3	Arrangement of curved prestressing steel.....	56
10.1.4	Arrangement of anchorages and couplers.....	56
10.1.5	Protection of anchorage zone.....	56
10.1.6	Reinforcement of concrete near anchorages.....	56
10.2	Steel reinforcement.....	56
10.2.1	Clear distance.....	56
10.2.2	Concrete cover.....	57
10.2.3	Bend configurations of reinforcement.....	57
10.2.4	Splices in reinforcement.....	59
10.2.5	Anchoring of reinforcement.....	60
10.2.6	Welded wire fabric.....	61
10.3	Concrete joints.....	61
10.3.1	Construction joints.....	61
10.3.2	Joints between precast concrete members.....	62
10.4	Reinforcement for opening.....	62
11	Design of members.....	63
11.1	Method of calculating member force.....	63
11.1.1	Analysis method.....	63
11.1.2	Analysis model.....	63
11.2	Component division.....	65
11.3	Roof.....	65
11.3.1	Structural types.....	65
11.3.2	Design in general.....	66
11.4	Tank wall.....	72
11.4.1	Structural types.....	72
11.4.2	Design in general.....	74
11.5	Base slab.....	91
11.5.1	Structural types.....	91
11.5.2	Design in general.....	92
12	Materials.....	96
12.1	Quality of materials.....	96
12.1.1	General.....	96
12.1.2	Concrete materials.....	96
12.1.3	Concrete.....	97
12.1.4	Prestressing steel.....	97
12.1.5	Steel reinforcement.....	97

12.1.6	Welded wire fabric.....	97
12.1.7	Anchorage and couplers.....	97
12.1.8	Sheath.....	97
12.1.9	Coating materials for protecting prestressing steel.....	98
13	Tank appurtenances.....	98
13.1	Ladders/stairs and handrails.....	98
13.2	Manhole and water pilot hole.....	99
13.3	Ventilators.....	99
13.4	Lightning rods.....	99
13.5	Piping.....	99
13.6	Catch basin.....	100
13.7	Water-level gauge.....	100
13.8	Rainwater treatment.....	100
13.9	Protection equipment.....	100
Annex A (informative) Reference design flow.....		101
Annex B (informative) Design seismic coefficients for the seismic coefficient method.....		103
Annex C (informative) Seismic input for design by dynamic analysis.....		106
Annex D (informative) Example of material specifications.....		108
Annex E (informative) Example of design calculation.....		112
Bibliography.....		174

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see the following URL: www.iso.org/iso/foreword.html. (standards.iteh.ai)

This document was prepared by Technical Committee ISO/TC 71, *Concrete, reinforced concrete and prestressed concrete*, Subcommittee SC 5, *Simplified design standard for concrete structures*.

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Introduction

The aim of this document is to provide rules for the design and construction of prestressed concrete water tanks to be built in less-developed areas of the world. The design rules are based on simplified worldwide-accepted strength models. This document is self-contained; therefore actions (loads) and simplified analysis procedures are included, as well as minimum acceptable construction practice guidelines.

A great effort was made to include self-explanatory tables, graphics and design aids to simplify the use of this document and provide procedures. Notwithstanding, the economic implications of the conservatism inherent in approximate procedures as a substitution to sound and experienced engineering should be a matter of concern to the designer who employs this document and to the owner who hires him.

A prestressed concrete tank for potable water generally comprises the roof, wall and base slab. The roof is made to entirely cover the top of the cylindrical wall so as to protect the water from contamination with rainwater, etc. In many cases, it is made in the form of a dome shaped like a convex disc cut off from a sphere. The wall is a vertical cylinder that forms a container for water in combination with the flat disc base slab. Normally, only the wall of a prestressed concrete water tank is made with prestressed concrete, while the roof and base slab are made with reinforced concrete. Prestress is generally applied to the wall using prestressing steel in the vertical and circumferential directions, but in some cases prestress is applied only to the circumferential direction. For this reason, this document defines a prestressed concrete cylindrical tank as a structure having prestressing steel at least in the circumferential direction of the wall to apply prestress, so as to cover both types. Therefore, the roof, base slab and wall in the vertical direction may not necessarily be of prestressed concrete construction but may be of reinforced concrete construction.

A prestressed concrete water tank construction is generally adopted to preserve a water storage facility with the aim of preventing severe secondary disasters and allowing the standing water to be used as an emergency water supply. For this reason, it is required to be designed as a rule as a high degree of importance.

The minimum dimensional provisions contained in this document are intended to account for undesirable side effects that will require more sophisticated analysis and design procedures. Material and construction provisions are aimed at site-mixed concrete, as well as ready-mixed concrete and steel of the minimum available strength grades.

The earthquake-resistance provisions are included to account for the fact that numerous underdeveloped regions of the world occur in earthquake-prone areas. The earthquake resistance is based upon the employment of structural concrete walls (shear walls) that limit the lateral deformations of the structure and provide for its lateral strength.

This document contains provisions that can be modified by the National Standards Body due to local design and construction requirements and practices. The specifications that can be modified are indicated using ["boxed values"]. The National Standards Body is expected to review the "boxed values" and may substitute alternative definitive values for these elements for use in the national application of this document.

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Simplified design of prestressed concrete tanks for potable water

1 Scope

This document provides guidelines for the planning, design and construction of a cylindrical tank constructed on the ground with prestressed concrete (PC) for use with potable water tank.

This document is applicable to PC tanks for potable water with a capacity of 30 000 m³ or less and the diameter-to-height ratio (D/H) from 1,0 to 3,0.

NOTE When designing and constructing a tank not covered by this document (reinforced concrete tanks, underground tanks, elevated tanks, etc.), a designer can refer to this document for common elements where possible.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 1920-3, *Testing of concrete — Part 3: Making and curing test specimens*

ISO 1920-4, *Testing of concrete — Part 4: Strength of hardened concrete*

ISO 6934-1, *Steel for the prestressing of concrete — Part 1: General requirements*

ISO 6934-2, *Steel for the prestressing of concrete — Part 2: Cold-drawn wire*

ISO 6934-3, *Steel for the prestressing of concrete — Part 3: Quenched and tempered wire*

ISO 6934-4, *Steel for the prestressing of concrete — Part 4: Strand*

ISO 6934-5, *Steel for the prestressing of concrete — Part 5: Hot-rolled steel bars with or without subsequent processing*

ISO 6935-1, *Steel for the reinforcement of concrete — Part 1: Plain bars*

ISO 6935-2, *Steel for the reinforcement of concrete — Part 2: Ribbed bars*

ISO 6935-3, *Steel for the reinforcement of concrete — Part 3: Welded fabric*

ISO 12439, *Mixing water for concrete*

ISO 14654, *Epoxy-coated steel for the reinforcement of concrete*

ISO 14824-3, *Grout for prestressing tendons — Part 3: Test methods*

3 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

**3.1
bending analysis**

method for determining the membrane force and bending moment in consideration of the boundary conditions at the base of the dome

**3.2
clearance**

distance between the designed high-water level and the upper edge of the tank wall

**3.3
convective pressure**

water pressure produced by oscillation of the water

**3.4
cylindrical prestressed concrete tank**

concrete tank comprising the roof, cylindrical wall and base slab, for which prestressing steel is provided at least in the circumferential direction to apply prestress

**3.5
disc part**

part other than the ring plate of the base slab that resists bending moments

**3.6
dome ring**

circular beam provided along the base of the roof of a spherical or other shape of the dome to control radial displacement at the base of the roof

**3.7
dynamic water pressure**

water pressure due to the effect of an earthquake

**3.8
embedded system**

system of applying prestress, whereby circumferential prestressing steel is provided within concrete members

**3.9
fixed support**

wall-bottom connection whereby the rotation or horizontal displacement of the wall with respect to the bottom is not allowed

**3.10
foundation slab**

reinforced concrete or prestressed concrete slab provided in contact with the bottom surface of the base slab

**3.11
freely sliding support**

wall-bottom connection, whereby the rotation and horizontal displacement of the wall with respect to the bottom are allowed

**3.12
hinged support**

wall-bottom connection, whereby the rotation of the wall with respect to the bottom is allowed

**3.13
hoop tension**

circumferential axial tensile force generated by such loads as water pressure

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3.14**horizontal thrust**

horizontal component of the axial force in the meridian direction of the dome at the base of the dome

3.15**Housner method**

conventional approximate analysis method for liquid vibration proposed by G. W. Housner

3.16**imposed load**

load of portions not included in the design calculation as structural members and load applied to the roof for such purposes as inspection

3.17**impulsive pressure**

dynamic water pressure (3.7) in response to short-period components of an earthquake and water pressure associated with inertial force produced by accelerations of the tank wall and directly proportional to these accelerations

3.18**inertia force**

force given by the product of the weight of a body and the design seismic intensity

3.19**in-plane shear force**

shear force that acts parallel to the shell surface

3.20**membrane floor**

part other than the ring plate of the base slab that does not resist bending moments

3.21**membrane force**

in-plane axial force of a shell structure

3.22**out-of-plane shear force**

shear force that acts at a right angle to the shell surface

3.23**particular load**

special load that acts depending on the natural conditions of the tank construction site

Note 1 to entry: Particular load is judged as a *primary load* (3.25) or a *subsidiary load* (3.31) on a case-by-case basis.

3.24**pilaster**

rectangular projections from the tank wall along its generatrix lines for anchoring circumferential prestressing steel

3.25**primary load**

load that constantly acts

3.26**ring plate**

peripheral part of the base slab for transmitting forces primarily from the tank wall to the ground

3.27

sloshing

vibration of a solid oscillating surface generated in response to relatively long-period components of an earthquake

3.28

solid mass of water

equivalent weight of water to produce the impulsive force on the tank wall

Note 1 to entry: It is assumed to be fastened rigidly to the tank wall.

3.29

solid oscillating mass

equivalent oscillating weight to produce the convective force on the wall

Note 1 to entry: It is assumed to be fastened to the tank wall by spring.

3.30

spherical dome

curved shell in the form of a part of a sphere cut off by a plane

3.31

subsidiary load

load that rarely acts

3.32

tank empty condition

state in which no water is present in the tank

3.33

tank full condition

state in which the water level in the tank reaches the design high water level

3.34

velocity potential method

method for a theoretical solution to irrotational vibration of a non-compressive and non-viscous fluid

3.35

waterstop

plate inserted in joints between concrete lifts and the wall-bottom joints for waterstopping

4 Symbols

A	projection area
A_b	area of concrete subjected to bearing load
A_c	total area of concrete surface
A_d	surface area of the dome
A_{EP}	area subjected to the effect of anchorage set
A_i	cross-sectional area of element i (member between nodes i and $i + 1$)
A_p	cross-sectional area of prestressing steel
A_s	cross-sectional area of tensile reinforcement
b	member width

C	wind force coefficient
C_e	earth pressure coefficient
C_s	structure characteristic coefficient
C_z	correction factor by region
D	diameter of the tank
D_{he}	correction factor dependent on damping constant
D_i	flexural stiffness of node i $\left(= \frac{Et_i^3}{12(1-\nu^2)} \right)$
D_p	pile diameter
D_η	response reduction ratio due to plastic deformability
E	elastic modulus
E_c	elastic modulus of concrete
E_p	elastic modulus of prestressing steel
E_s	elastic modulus of steel reinforcement
f'_{cd}	design compressive strength of concrete
f'_{ck}	characteristic compressive strength of concrete
f_{pu}	tensile strength of prestressing steel
f_{py}	yield strength of prestressing steel
f_{sy}	yield strength of steel reinforcement
f_{ud}	design tensile strength of prestressing steel
f_{yd}	design yield strength of steel reinforcement and structural steel
g	gravitational acceleration
g_0	uniform pressure
H	height or total water depth of the tank
H_G	distance from the bottom of the tank wall to the point of action of the dome inertia force or other partial weight inertia force
H_h	length of thickened wall (haunch height)
H_i	thickness of i -th stratum
H_s	total height of earth pressure action
H_t	horizontal thrust
H_x	water depth at an arbitrary point

h	height from the ground surface
h_{rE}	distance from tank bottom to a solid mass point when dynamic water pressure on base slab is neglected
h_{rI}	distance from tank bottom to a solid mass point when dynamic water pressure on base slab is considered
h_{sE}	distance from tank bottom to solid oscillating mass point when dynamic water pressure on base slab is neglected
h_{sI}	distance from tank bottom to solid oscillating mass point when dynamic water pressure on base slab is considered
h_{th}	virtual thickness of member
I_i	second moment of area of element i (member between nodes i and $i + 1$)
J_1	vessel function
K	flexural stiffness $\left(= \frac{E t^3}{12(1-\nu^2)} \right)$
K_h	design horizontal seismic coefficient
K_{ho1}	standard horizontal seismic coefficient of structure for Level 1 ground motion
K_{ho2}	standard horizontal seismic coefficient of structure for Level 2 ground motion
K_{h1}	design horizontal seismic coefficient for Level 1 ground motion
K_{h2}	design horizontal seismic coefficient for Level 2 ground motion
K_v	vertical subgrade reaction modulus
K_{vi}	vertical spring constants of node i
$K_{\theta i}$	rotational spring constants of node i
k	spring constant of bearing
k_α	coefficient incorporating the characteristics of foundations
k_β	coefficient incorporating the characteristics of base slab
L_{rp}	ring plate width
L_w	water depth
l	length from the tension end of prestressing steel to the design cross-section
l_d	basic development length
l_{max}	maximum spacing of prestressing steel
l_p	length of prestressing steel
l_1	distance from the top of wall to the beginning point of action of distributed load

l_2	distance from the top of wall to the end point of action of distributed load
Δl	set length
M_a	corrected vertical bending moment
M_d	vertical bending moment of member
M_e	vertical bending moment at the bottom of the tank wall generated by changes in the curvature radius of the tank wall
M_{ud}	design flexural fracture capacity
M_x	vertical bending moment
M_{xi}	bending moment at node i determined by planar frame analysis
$M_{x\phi}$	torsional moment
M_0	restraining moment at the bottom of the tank wall
M_{0c}	vertical bending moment at the bottom of the tank wall with a constant thickness
M_{0e}	vertical bending moment at the bottom of the tank wall generated by curvature changes when the wall thickness is constant at t
M_{0f}	vertical bending moment at bottom of the tank wall
M_{0h}	vertical bending moment at the bottom of the tank wall incorporating increases in the wall bottom thickness
$M_{0T}(x)$	overturning moment at a distance x from the top of the tank wall
M_{0v}	vertical bending moment at the bottom of the tank wall generated by the effect of Poisson's ratio due to vertical prestress, v , when the wall thickness is constant
\overline{M}_x	vertical bending moment obtained from axisymmetric analysis under equivalent load
M_ϕ	circumferential bending moment
$M_{\phi x}$	torsional moment
$M_{\theta i}$	bending moment per unit length in the circumferential directions
N_x	axial force in the vertical direction
$N_{x0}(x)$	vertical axial force at distance from the bottom of the tank wall
$N_{x\phi}$	in-plane shear force
N_ϕ	axial force in the circumferential direction
$N_{\phi d}$	membrane force per unit length of the dome in the meridian direction
$N_{\phi x}$	in-plane shear force
$N_{\theta d}$	membrane force per unit length of the dome in the parallel direction
n	elastic modulus ratio ($=E_p/E_c$)
P	prestressing force in the vertical direction