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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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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.

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*.

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.

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 m^3 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

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 $\left(= \dfrac{E t_i^3}{12\left(1 - \nu^2\right)} \right)$

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 lab 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 $\left(= \dfrac{E t^3}{12\left(1 - \nu^2\right)} \right)$

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

$M_{0\nu}$ vertical bending moment at the bottom of the tank wall generated by the effect of Poisson's ratio due to vertical prestress, ν, 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

$N_{xo}(x)$ 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