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Designing of cylindrical concrete tanks with regard to buckling and second order effects

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Abstract

Structural designing of reinforced concrete structures consists in determination of the cross section height and amount of the vertical and horizontal reinforcement on the basis of the internal forces. These forces are not determined correctly without considering the structure deformation. It means that the geometric type nonlinearity should be regarded at least. In the case of compression the buckling and the so called “second order effects” should be taken into account . The EC2-1-1 code gives the general rules for such effects, but they are described in details only for columns and buildings. Therefore the aim of this paper is to formulate recommendations which will be useful for reinforced concrete cylindrical tanks for liquids and particulate solids compressed vertically (meridional compression) and horizontally (hoop compression). These recommendations are formulated on the basis of nonlinear FEM analysis, which is preceded by analysis of expressions describing the critical stress of cylinders, formulated by theory of elasticity.

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Keywords: Concrete tanks, buckling, second order effects, FEM analysis

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1. Introduction

The walls of reinforced concrete tanks and silos may be tensioned or compressed. The horizontal (hoop) compression occurs in the empty underground or underwater tanks. Horizontal compression may be also caused in cylindrical tanks by prestressing. The vertical (meridional) forces are compressive in tank walls supported directly on the plate or continuous basement.

Nomenclature

N_v	meridional axial force in the tank wall due to vertical force exerted on the upper edge of tank wall and its self-weight, determined for unit cross section *kN/m*
P_v	vertical force exerted on the upper edge of tank wall determined for unit cross section, *kN/m*
$P_{v,crit}$	critical value of vertical force exerted on the upper edge of tank, determined for unit cross section, *kN/m*
p, p_{crit}	vertical pressure exerted onto upper edge of the tank wall ($p = P_v/t$) and its critical value, kN/m^2
R_h	horizontal axial hoop force due to lateral pressure, determined for unit cross section ($R_h = qr$), *kN/m*
q, q_{crit}	horizontal (lateral) pressure exerted on the tank wall from outside and its critical value, kN/m^2
t	thickness of cylindrical wall, *m*
r, l	radius and length of cylindrical structure, *m*
E, E_t	secant and tangent modulus of structural material
ν	Poisson coefficient of structural material
M_{Ed}	total design bending moment
M_{0Ed}	first order design bending moment
N_{Ed}	design value of axial load
N_B	buckling load based on nominal stiffness
β	factor which depends on distribution of 1st and 2nd order effects
E_{cm}, E_{cd}	mean (secant) and design values of concrete modulus
E_s	design value of modulus of elasticity of reinforcing steel
f_{cm}	mean value of concrete compressive strength
I_c	moment of inertia of concrete cross section
I_s	second order moment of area of reinforcement about centre of concrete area

While considering the horizontal or vertical compression the second order effects and buckling should be taken into account. Such a recommendation was also formulated for concrete cylindrical tanks in [1] and even for prestressed cylindrical tanks and silos in [2]. In these books, the equations describing the critical forces and critical stress were quoted from theory of elasticity.

On the other hand, EC2-1-1 [3] gives the general rules for buckling and second order effects for the members under compression, but they are described in details only for columns and buildings.

The two above-mentioned circumstances inspired the authors to undertake the buckling problem in concrete cylindrical tanks and silos. The authors intended to present the up-to-date problem considerations and formulate some recommendations for designers. The FEM analyses were performed with use of software Autodesk Simulation Mechanical 2017 [4].

2. EC2-1-1 basic rules for buckling and second order effects

Buckling is defined by EC2-1-1 as the failure due to instability of a member or structure, under perfectly axial compression and without transverse load. "Pure buckling" is not a relevant limit state in real structures, due to imperfections and transverse loads.

For the stability analysis EC2-1-1 code recommends general method - the non-linear second-order analysis (based on standard "σ_c- ε_c" relationship and consequently tangent concrete modulus) and two simplified methods (based on the mean value of secant concrete modulus).