Guide for the Analysis, Design, and Construction of Elevated Concrete and Composite Steel-Concrete Water Storage Tanks

Reported by ACI Committee 371

ACI 371R-16

American Concrete Institute
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First Printing
June 2016
ISBN: 978-1-945487-00-2

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This guide presents recommendations for materials, analysis, design, and construction of concrete-pedestal elevated water storage tanks, including all-concrete and composite tanks. Composite tanks consist of a steel water storage vessel supported on a cylindrical reinforced concrete pedestal.

Concrete-pedestal elevated water storage tanks are structures that present special problems not encountered in typical environmental engineering concrete structures. This guide refers to ACI 350 for design and construction of those components of the pedestal tank in contact with the stored water, and to ACI 318 for design and construction of components not in contact with the stored water. Determination of snow, wind, and seismic loads based on ASCE/SEI 7 is included. These loads conform to the requirements of national building codes that use ASCE/SEI 7 as the basis for environmental loads as well as those of local building codes. Special requirements, based on successful experience, for the unique aspects of loads, analysis, design, and construction of concrete-pedestal tanks are presented.

Keywords: composite tanks; concrete-pedestal tanks; earthquake-resistant structures; elevated water tanks; formwork (construction).

CONTENTS

ACI 371R-16 supersedes ACI 371R-08 and was adopted and published June 2016.

CHAPTER 1—GENERAL

1.1—Introduction

This guide provides recommendations for the design and construction of elevated concrete and composite steel-concrete water storage tanks based on practices used in successful projects. Elevated tanks are used by municipalities and industry for potable water supply and fire protection. Commonly built sizes of elevated concrete and composite steel-concrete water storage tanks range from 500,000 to 3,000,000 gal. (1900 to 11,000 m^3). Concrete pedestal heights range from 25 to 200 ft (8 to 60 m), depending on water system requirements and site elevation. The interior of the concrete pedestal may be used for material and equipment storage, office space, and other applications.

Since the 1970s, concrete-pedestal elevated water storage tanks have been constructed in North America with a steel water-containing element and an all-concrete support structure. The generic term "composite elevated tank" is often used to describe tanks of this configuration. A few all-concrete elevated tanks have been built in the United States throughout the last century, as well as a few elevated prestressed tanks jacked into place. Elevated post-tensioned tanks as detailed in this guide have a long history in Europe, and were introduced to the U.S. market in the 1990s.

All-concrete and composite steel concrete elevated tanks are competitively marketed as complete entities, including design, and are constructed under design-build contracts using proprietary designs, details, and methods of construction. The designs, however, are frequently reviewed by owners and their consulting engineers, or by city or county officials.

Elevated tanks designed and constructed in accordance with the recommendations of this guide are expected to be durable structures that require only routine maintenance. Details of concrete surfaces that promote good drainage and avoid low areas conducive to ponding essentially eliminate the problems associated with cyclic freezing and thawing of fresh concrete in cold climates. The quality of concrete for elevated tanks in this guide meets the requirements for durable concrete as defined in ACI 201.2R. It has adequate strength, a low water-cementitious materials ratio (*w*/*cm*), and air entrainment for frost exposure. The concrete support structure loads are primarily compressive with little or no cyclic loading with stress reversal.

1.2—Scope

Recommendations supplement the general requirements for reinforced concrete and prestressed concrete design and construction given in ACI 318, ACI 301, ACI 350, and ACI 350.5. Design and construction recommendations include materials, determination of structural loads, design of concrete elements including foundations, design of concrete or steel tank components, construction requirements, geotechnical requirements, appurtenances, and accessories. Materials, design, fabrication, and construction of the steel vessel of composite steel-concrete tanks are addressed by applicable sections of AWWA D100.

Design and construction recommendations are presented for the types of elevated concrete and composite steel-concrete water storage tanks shown in Fig. 1.2a and 1.2b. The elevated concrete tank consists of a post-tensioned concrete vessel on a cast-in-place concrete pedestal. The composite steel-concrete tank consists of a steel vessel on a cast-in-place concrete pedestal.

This guide may be used in whole or part for other tank configurations; however, the designer should determine the suitability of such use for other configurations and details.

1.3—Construction documents

Construction documents should show all features of the work, including:

(a) Tank capacity
(b) Codes and standards used in design
(c) Design basis and loads used in design
(d) Size and position of structural components and reinforcement
(e) Structural details
(f) Specified concrete compressive strength

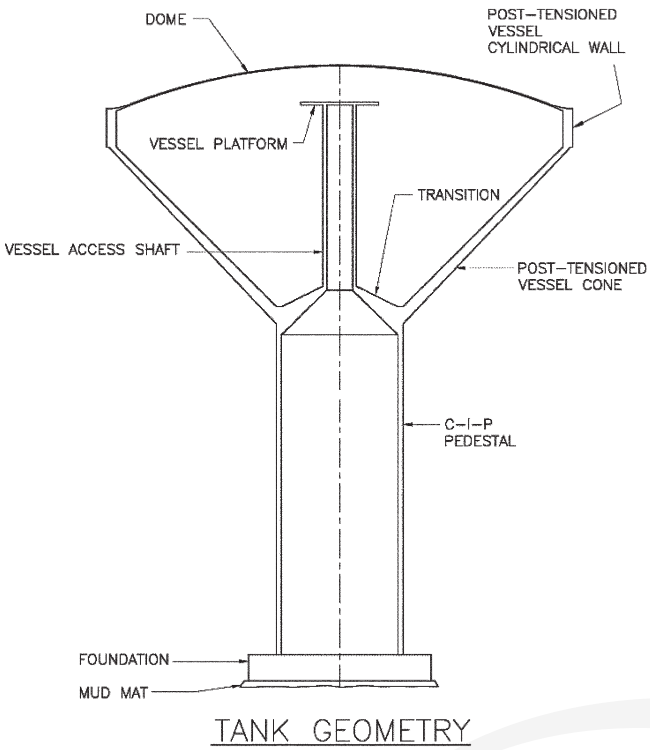

Fig. 1.2a—Common configuration of elevated concrete tanks.

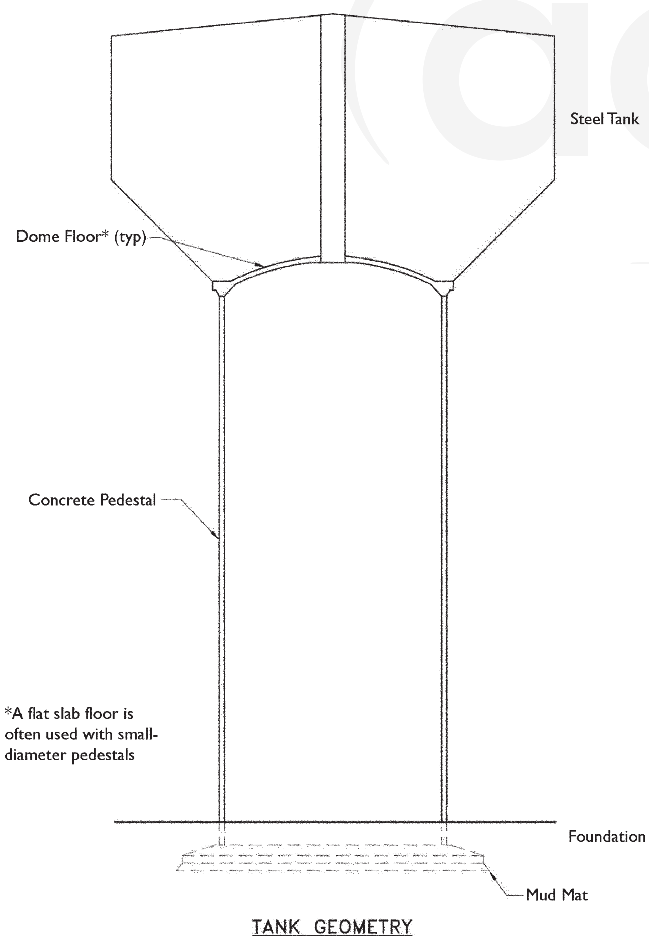

Fig. 1.2b—Common configuration of elevated composite steel-concrete tanks.

Fig. 1.4a—Completed composite elevated tank (photo courtesy of Landmark).

(g) Strength or grade of reinforcement and structural steel

Where the tank builder is providing both design and construction of the tank, full calculations detailing the structural aspects of the tank should be provided to the owner or owner's agent.

1.4—Sample tank photos

This section presents photographs of numerous varieties of tanks (Fig. 1.4a to 1.4h).

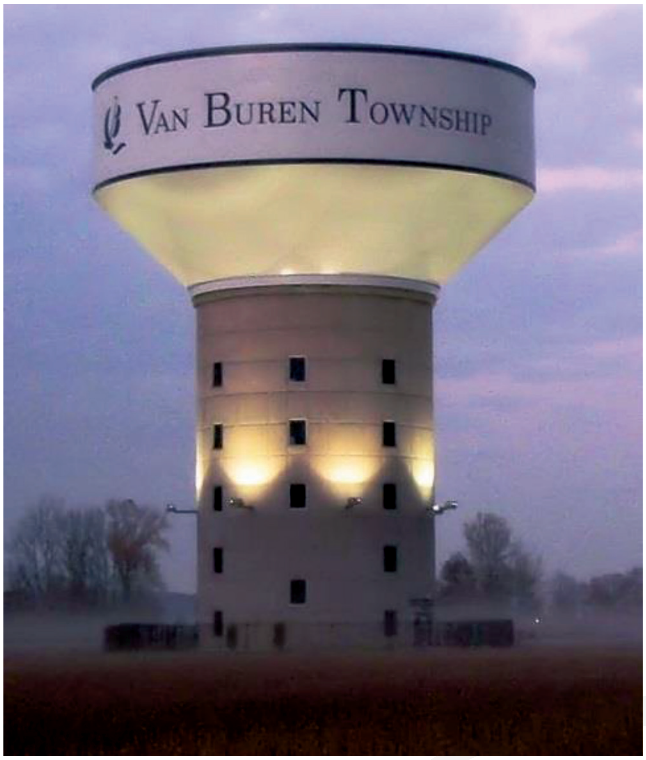

Fig. 1.4b—Completed composite elevated tank (photo courtesy of CBI).

Fig. 1.4c—Completed composite elevated tanks (photo courtesy of Caldwell Tanks, Inc.).

Fig. 1.4d—Completed concrete elevated tank (photo courtesy of Crom LLC).

Fig. 1.4e—Construction of composite elevated tank (photo courtesy of Landmark).

Fig. 1.4f—Construction of composite elevated tank pedestal (photo courtesy of CBI).

Fig. 1.4g—Construction of composite elevated tank pedestal (photo courtesy of Caldwell Tanks, Inc.).

Fig. 1.4h—Construction of concrete elevated tank (photo courtesy of Crom LLC).

CHAPTER 2—NOTATION AND DEFINITIONS

2.1—Notation

A = area
A_c = area of gross section of pedestal
A_{cv} = concrete shear area of a section, in.^{2} (mm^2)
A_f = horizontal projected area of a portion of the structure where the wind force coefficient C_f and the wind pressure p_z are constant, in.^{2} (mm^2)
A_g = gross concrete area of a section, in.^{2} (mm^2)
A_s = area of nonprestressed tension reinforcement, in.^{2} (mm^2)
A_t = cross-sectional area of vessel at mid-depth of water
A_w = gross horizontal cross-sectional concrete area of wall, in.^{2} (mm^2), per unit length of circumference, ft (m)
b_d = width of a doorway or other opening, in. (mm)
b_v = equivalent shear wall length not to exceed $0.78d_w$, in. (mm)
b_x = cumulative opening width in a distance of b_v, in. (mm)
C = buckling parameter for thin metal cylinders that buckle with diamond-shaped pattern
C_c = spectral acceleration of sloshing liquid
C_e = eccentricity coefficient that accounts for the resultant of factored axial load being eccentric to the centroid of the pedestal thickness
C_{es} = snow load exposure factor
C_f = wind force coefficient
C_s = seismic response coefficient
C_{sm} = modal seismic design coefficient for mode m
C_{vx} = seismic distribution factor
C_{vxm} = seismic distribution factor of the m-th mode
c_c = clear cover from the nearest surface in tension to the surface of the flexural torsion reinforcement, in. (mm)
D = dead load
D_t = tank diameter at the water surface, ft (m)
d_c = distance from the closest face to the centroid of the tension reinforcement, in. (mm)
d_w = mean diameter of concrete pedestal, ft (m)
E = combined effect of horizontal and vertical earthquake forces
E_c = modulus of elasticity for concrete, psi (MPa)
E_{cr} = modulus of elasticity for concrete to allow for microcracking and creep, psi (MPa)
e = eccentricity of the axial wall load, in. (mm)
e_g = vertical load eccentricity, in. (mm)
e_o = minimum vertical load eccentricity, in. (mm)
F = weight and pressure of stored water
F_a = seismic acceleration-based site coefficient
F_i = portion of the total seismic shear V acting at level i, kip (kN)
F_s = factor of safety against buckling
F_v = seismic-velocity-based site coefficient
F_x = portion of the seismic shear V acting at level x, kip (kN)
F_{xm} = modal force at each level, kip (kN)
F_z = wind force acting on tributary area A_f, kip (kN)
f_c = concrete compressive stress
f_{ca} = average compression stress
f_c' = specified compressive strength of concrete, psi (MPa)