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Design and Construction of Circular Prestressed Concrete Structures with Circumferential Tendons

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FOREWORD

This report provides recommendations for the design and construction of circular prestressed concrete structures (commonly referred to as "tanks") post-tensioned with circumferential tendons. These thin cylindrical shells of either cast-in-place or precast concrete are commonly used for liquid and bulk storage. Vertical post-tensioning is often incorporated in the walls as part of the vertical reinforcement. Recommendations are applicable to circumferential prestressing achieved by post-tensioning tendons placed within the wall or on the exterior surface of the wall. Procedures to prevent corrosion of the prestressing elements are emphasized. The design and construction of dome roofs are also covered.

Keywords: circumferential prestressing; concrete; corrosion resistance; domes; floors; footings; joints; loads (forces); prestressed concrete; prestressed reinforcement; reinforcing steel; roofs; shotcrete; shrinkage; tanks; temperature; tendons; walls.

CONTENTS

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CHAPTER 1—GENERAL

1.1—Introduction

The design and construction of circular prestressed concrete structures using tendons requires specialized engineering knowledge and experience. This report reflects over four decades of experience in designing and constructing circular prestressed concrete structures with tendons. When designed and constructed by knowledgeable individuals, these structures can be expected to serve for fifty years or more without requiring significant maintenance.

This report is not intended to prevent development or use of new advances in the design and construction of circular prestressed concrete structures. This report is not intended for application to nuclear reactor pressure vessels or cryogenic containment structures.

This report describes current design and construction practices for tanks prestressed with circumferential post-tensioned tendons placed within or on the external surface of the wall.

1.2—Objective

The objective of this report is to provide guidance in the design and construction of circular prestressed concrete structures circumferentially prestressed using tendons.

1.3—Scope

The recommendations in this report are intended to supplement the general requirements for reinforced concrete and prestressed concrete design, materials and construction, given in ACI 318, ACI 301 and ACI 350R.

This report is concerned principally with recommendations for circular prestressed concrete structures for liquid storage. The recommendations contained here may also be applied to circular structures containing low-pressure gases, dry materials, chemicals, or other materials capable of creating outward pressures. The recommendations may also be applied to domed concrete roofs over other types of circular structures. Liquid storage materials include water, wastewater, process liquids, cement slurry, petroleum, and other liquid products. Gas storage materials include gaseous by-products of waste treatment processes and other gaseous material. Dry storage materials include grain, cement, sugar, and other dry granular products.

The recommendations in this report may also be applicable to the repair of tanks using externally applied tendons.

Design and construction recommendations cover the following elements or components of tendon tanks:

a. Floors
- Prestressed Concrete
- Reinforced Concrete

b. Floor-Wall Joints
- Hinged
- Fixed
- Partially Fixed
- Unrestrained
- Changing Restraint

c. Walls
- Cast-in-Place Concrete
- Precast Concrete

d. Wall-Roof Joints
- Hinged
- Fixed
- Partially Fixed
- Free

e. Roofs
- Concrete Dome Roofs with Prestressed Dome Ring
  (1) Cast-in-place Concrete.
  (2) Shotcrete.
- Other Roofs
  (1) Prestressed Concrete.
  (2) Reinforced Concrete.

f. Wall and Dome Ring Prestressing Methods
- Circumferential

(1) Individual high-strength strands in plastic sheaths or multiple high-strength strand tendons in ducts positioned within the wall and post-tensioned after placement and curing of the wall concrete, as shown in Fig. 1.1.

(2) Individual or multiple high-strength strands and, less frequently, individual high-strength bar tendons, prestressed after being positioned on the exterior surface of the wall.

- Vertical

(1) Individual or multiple high-strength strand or individual high-strength bar tendons, enclosed in sheathing or ducts within the wall, anchored near the wall joints at the bottom and top of the wall.

(2) Pretensioned high-strength strands in precast panels.

1.4—History and development

The late Eugene Freyssinet, a distinguished French engineer generally regarded as the father of prestressed concrete, was the first to recognize the need to use steels of high quality and strength, stressed to relatively high levels, in

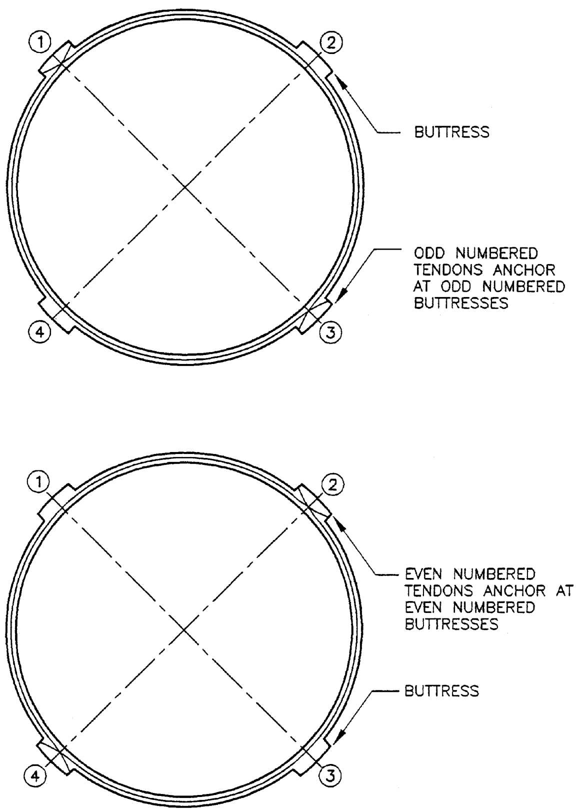

Fig. 1.1—Typical tendon layout.

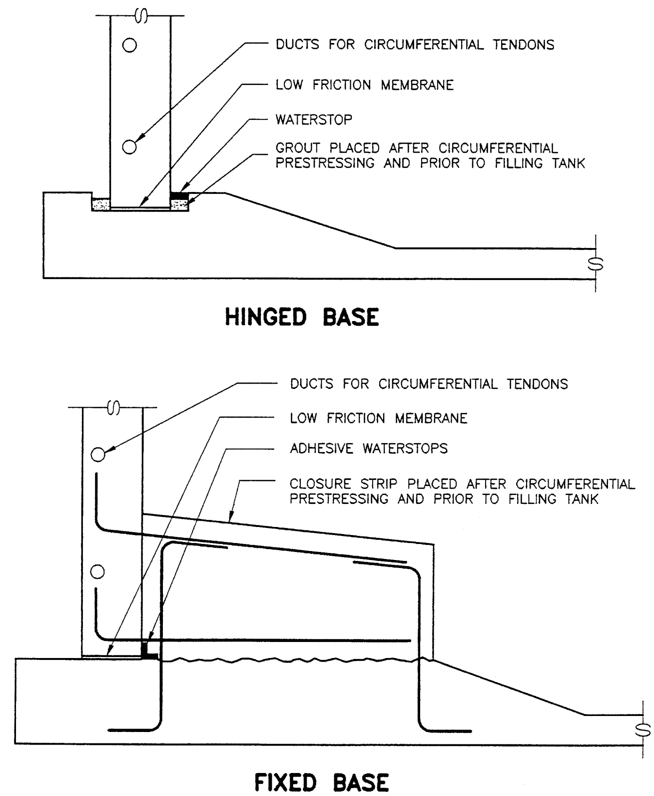

Fig. 1.2—Typical base restraint details.

order to overcome the adverse effects of concrete creep and shrinkage. Freyssinet successfully applied prestressing tendons to concrete structures as early as the late 1920s.

The earliest use of circumferential tendon prestressing in the United States is attributed to the late W. S. Hewett in 1923. He designed and had built several reservoirs using circumferential rods and turnbuckles. A 1932 concrete standpipe in Minneapolis, MN[20] prestressed by tendons, designed with the Hewett System is still in use and in good condition.

In the early 1950s, following methods used successfully in Europe for a number of years, several circular prestressed concrete tanks were constructed in the United States using post-tensioned high tensile-strength wire tendons embedded in the tank walls. The post-tensioned tendons in most early “tendon tanks” were grouted with a portland cement-water mixture after stressing to help protect them against corrosion and to bond the tendons to the concrete tank walls. Others were unbonded paper-wrapped individual wire or strand tendons that depended on a grease coating and the cast-in-place concrete for their corrosion protection. Later, the use of unbonded tendons with corrosion-inhibiting grease coatings and plastic sheaths became more common. Most of the early tendon tanks constructed in the U.S. followed the common European practice of vertically prestressing the tank walls to eliminate or control horizontal cracking. This crack control helped prevent leakage of the contents and corrosion of the prestressing steel.

Several hundred tendon-stressed tanks (with bonded and unbonded tendons) have been constructed in the United States.

1.5—Definitions

1.5.1 *Core wall*—That portion of a concrete wall that is circumferentially prestressed. Does not include the shotcrete covercoat in an externally post-tensioned tank.

1.5.2 *Joint restraint conditions*—Bottom and top boundary conditions for the cylindrical shell wall. Examples are shown in Fig. 1.2 and 1.3.

1.5.2.1 *Hinged*—Full restraint of radial translation and negligible restraint of rotation.

1.5.2.2 *Fixed*—Full restraint of radial translation and full restraint of rotation.

1.5.2.3 *Partially fixed*—Full restraint of radial translation and partial restraint of rotation.

1.5.2.4 *Unrestrained*—Limited restraint of radial translation and negligible restraint of rotation (free).

1.5.2.5 *Changing restraint*—A joint may be of a different type during and after prestressing. An example is a joint that is unrestrained (free) during prestressing but is hinged after prestressing. The change in joint type is a result of grout installation that prevents radial translation after prestressing.

1.5.3 *Membrane floor*—A thin, highly reinforced, slab-on-grade designed to deflect when the subgrade settles and still retain liquid-tightness.

1.5.4 *Shotcrete cover*—Pneumatically-applied mortar covering external tendons.

1.5.4.1 *Tendon coat*—The part of a shotcrete cover in contact with the circumferential prestressing.

1.5.4.2 *Body coat*—The remainder of the shotcrete cover.

1.5.4.3 *Covercoat*—The tendon coat plus the body coat.