

Reinforced Concrete Cooling Tower Shells -Practice and Commentary

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This document is an updated report on the design and construction of reinforced concrete cooling tower shells. In general, this report is addressed to towers 300 ft (90 m) or greater in height having a geometric form similar to or that of a hyperboloid of revolution. The specific intent is to provide the design profession with guidelines reflecting the present state of the art, as interpreted by the committee.

Keywords bending; buckling; columns (supports); concrete construction; cooling towers; earthquake resistant structures; earthquakes; loads (forces); membrane theory (shells); reinforced concrete; reinforcing steels; shells (structural forms); splicing; stability; structural analysis; structural design; towers; ultimate strength method; wind pressure.

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ACI Committee Reports, Guides, Standard Practices, and Commentaries are intended for guidance in designing, planning, executing, or inspecting construction and in preparing specifications. Reference to these documents shall not be made in the Project Documents. If items found in these documents are desired to be part of the Project Documents, they should be phrased in mandatory language and incorporated into the Project Documents.

ACI 334.2R-91 supersedes ACI 334.2R-84.

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1 - GENERAL**1.1 - Scope**

This document is a report on the design and construction of reinforced concrete cooling tower shells, updating the earlier document ACI 334.2R that appeared first in 1977¹ with a minor revision in 1982. The report is addressed to towers 300 ft (90 m) or greater in height having a geometric form of a hyperboloid of revolution or similar. The intent is to provide the design profession with guidelines reflecting the present state of the art, as interpreted by the committee.

The report accepts the basic premise first expressed in the Shell Committee's 1964 report "Concrete Shell Structures: Practice and Commentary,"² "The analysis, design and construction of thin shell structures requires a thorough knowledge in this field. Therefore, the recommendations contained herein are not sufficient in themselves for the satisfactory execution of thin shell structures. Designers are referred to the many texts and technical papers that are readily available." In the spirit of **Reference 2**, the division into a Practice and a Commentary has been adopted here. Cognizance is also taken of the Recommendations of the International Association for Shell and Spatial Structures³ published in 1979. The ACI 307 specification is also cited for guidance.

It is not intended that this document serve as a code or standard practice. However, because of the nature of the cooling tower industry wherein cooling towers are often competitively marketed as complete entities including the design, a somewhat detailed, nonproprietary set of guidelines for the interpretation of the current state of the art in the design for cooling tower shells seems desirable. These guidelines do not include any judgment as to the appropriateness of different shapes or of the many possible ways to proportion cooling towers.

1.2 - Definitions

Bending analysis - An analysis of thin shells in which both bending and membrane action are taken into account.

Columns - Slender elements that transmit loads from the lintel to the plinths and provide openings for air passage into the cooling tower. Columns are typically arranged in V or X configurations.

Cornice - The upper edge of the shell.

Elastic analysis - An analysis of deformations and internal stresses based on equilibrium and assumed elastic behavior, and representing to some degree of approximation the three-dimensional action of the shell together with its auxiliary elements.

Experimental analysis - An analysis based on the measurement of deformations and/or strains of the structure or its model. Experimental analysis may be based on either elastic or inelastic behavior.

Fill - The medium that promotes heat transfer in a cooling tower. **Splash fills** consist of multitudes of horizontal bars staggered in elevation so that falling water is repeatedly impeded, broken into fine droplets, and spread into thin films over the bars. **Film fills** consist of many closely spaced vertical sheets providing for the formation of thin water films over a vast surface.

Foundation - A system of structural elements that supports the plinths and transmits loads to the ground. Foundation ring beams are typically used to resist symmetric horizontal thrusts primarily by hoop forces and to transmit other reaction components to other foundation elements or directly to the soil.

Lift - A ring segment of the reinforced concrete wall [typically 5 to 6 ft high (1.5 to 1.8 m)] constructed in a single forming stage and continuous concreting operation.

Lintel - An integral part of the shell that constitutes its lower edge. The lintel spans across the top of the support columns and provides the initial support for the shell forming system.

Membrane analysis - An approximate analysis of thin shells in which bending is neglected and only in-plane (membrane) stress resultants are taken into account.

Nonlinear strength analysis - An analysis that includes the effects of geometric and material nonlinearities, cracking, strain hardening of reinforcement, bond slip, and tension stiffening. This analysis generally is carried out incrementally for the entire load range.

Plinth - One of a number of pedestals or piers located around the base of the cooling tower at the foundation level.

Bibs - Continuous meridional elements projecting inward or outward from the shell surface, to provide roughness that reduces maximum negative wind pressure (suction) or to stiffen the shell.

Stiffening ring - Circumferential beam element that may be used at the top or bottom edges or at intermediate levels to stiffen the shell. Stiffening rings are characterized by sudden thickness changes, in contrast to gradual thickening of the shell.

Throat - The horizontal circle of the shell that has the minimum radius.

1.3 - Structural drawings and computations

Structural drawings and computations of the cooling towers should be prepared under the direction of, and signed by, a registered professional engineer.

1.4 - Regulations

1.4.1 - The design and construction of the cooling tower and its foundation should conform to the requirements of all ordinances and regulations of authorities having jurisdiction, except where such requirements are less stringent than the comparable recommendations in this report. In such cases, the provisions herein are preferred.

1.4.2 - Particular attention is drawn to the importance of obtaining the recommendation of the Federal Aviation Agency with respect to cooling tower heights, and aviation obstruction lighting and marking.

2 - MATERIALS

All materials and material tests should conform to ACI 301.

3 - CONSTRUCTION

3.1 - General

Concrete quality, methods of determining concrete strength, field tests, concrete proportions and consistency, mixing and placing, and forms and details of construction should be in accordance with ACI 301 where applicable, except as suggested otherwise.

3.2 - Concrete quality

3.2.1 - The water-cement ratio of the concrete should not exceed 0.50 by weight.

3.2.2 - The specified 28 day compressive strength of concrete should not be less than 4000 psi (27.6 MPa). In addition, the provisions of Section 3.3.5 should be satisfied.

3.2.3 - Air-entrained concrete should be used for all concrete work.

3.3 - Formwork

3.3.1 - The formwork should be designed by a competent engineer in accordance with ACI 347 to provide safety to operating personnel and produce a sound structure.

3.3.2 - Special care should be taken to insure a finish with an unstained, acceptable appearance.

3.3.3 - After removal of the form ties, the holes should be filled by grouting or another method approved by the engineer.

3.3.4 - If ties of material that will corrode are used and left in place after removal of forms, they should be recessed at least 1 in. (25 mm) into the surface of the shell on both sides and sealed by grouting or another method approved by the engineer of record.

3.3.5 - Before any formwork is removed, the concrete in the shell should be evaluated by a qualified engineer in accordance with a program that includes in-place testing and/or field-cured cylinders to determine

the concrete's adequacy to resist subsequent applied loading.

3.4 - Reinforcement placement

3.4.1 - Circumferential reinforcement is generally placed on the exterior side (the side closest to formwork) of the vertical steel. All reinforcement should be securely tied to prevent displacement of the steel during placement of the concrete. Circumferential reinforcement should be stretched and secured so that it cannot bulge or be displaced during the placing and working of the concrete, which could result in less than the suggested minimum concrete cover for the reinforcement.

3.4.2 - Vertical reinforcement projecting above the previously cast concrete should be supported to prevent the breaking of the bond between the reinforcement and the freshly placed concrete.

3.4.3 - The cover over the steel reinforcement should not be specified as less than $\frac{3}{4}$ in. (19 mm).

3.5 - Concrete placement

3.5.1 - Particular attention should be given to concrete placement because of the thin wall section and the presence of reinforcing steel. Consolidation of concrete should be by vibration; removal of air and water at the form surface should be by spading or vibration. All horizontal construction joints should be cleaned of laitance and dirt and should be moistened or treated before placement of new concrete.

3.5.2 - In the cooling tower shell, horizontal construction joints should be maintained at approximately uniform spacing throughout the height of the cooling tower. The point of discharge of the concrete into the forms should not be more than one lift above the concrete surface on which it is to be deposited.

3.6 - Concrete curing

It is preferable that all necessary patching and finishing of concrete be done immediately after the form has been raised. As soon as the surface treatment has been completed for each lift, both faces of concrete should be coated with a membrane curing compound, unless another method of curing is approved by the engineer of record.

3.7 - Tolerances

3.7.1 - Tolerances should be specified with respect to (a) slope deviation in any lift, (b) radius deviation, and (c) wall thickness variation. Reference is also made to ACI 117.

3.7.2 - Correction of errors within the specified tolerances should be made gradually.

3.7.3 - Dimensions should be determined by field measurements and checked against the specified tolerances.

3.7.4 - Exceptions to the specified tolerances should be investigated by an analysis as described in Sections 4.2.1 and 4.7.3.