

Design Recommendations for Precast Concrete Structures

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Recommendations for the design of precast concrete structures are presented. Design of individual members and of connections for the integration of members into structures are covered. Aspects of detailing, production, handling, erection, and strength evaluation that are related to design are also presented.

Keywords: anchorage (structural); bearing elements; composite construction (concrete to precast concrete); concrete construction; connections (structural); erection; fabrication; joints (junctions); load tests (structural); precast concrete; reinforced concrete; reinforcement; slabs; structural analysis; structural design; structural integrity; tolerances; volume changes; walls.

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Reference to this document shall not be made in contract documents. If items found in this document are desired by the Architect/Engineer to be a part of the contract documents, they shall be restated in mandatory language for incorporation by the Architect/Engineer.

VARIANCES BETWEEN DESIGN RECOMMENDATIONS FOR PRECAST CONCRETE STRUCTURES AND ACI 318-89

1. **Section 6.1** waives the requirements of ACI 318-89 Section 7.12 for precast one-way slabs not wider than 12 ft. Explanation is provided in ACI 550R Section 6.1.
2. **Section 6.2** modifies the requirements of ACI 318-89 Sections 14.3.1 through 14.3.3 and 14.3.5 for precast walls. Explanation is provided in ACI 550R Section 6.2.
3. **Section 8.2** waives the requirement of ACI 318-89 Section 12.11.1, which states that positive beam reinforcement is required to extend along the same face of the member into the support 6 in., if this would cause the reinforcement to extend beyond the end of the member. Explanation is provided in ACI 550R Section 8.2.
4. **Section 9.1** allows, under certain circumstances, waiving of the requirement of ACI 318-89 Section 7.5.1, which

ACI 550R-96 supersedes ACI 550R-93 and became effective January 1, 1996.
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states that reinforcement shall be placed before concrete is placed. Explanation is provided in ACI 550R Section 9.1.

5. **Section 12.3** waives ACI 318-89 Section 20.4.11. Explanation is provided in ACI 550R Section 12.3.

CONTENTS

Chapter 1—Scope, p. 550R-2

Chapter 2—General, p. 550R-2

Chapter 3—Distribution of forces due to gravity loads, p. 550R-3

Chapter 4—Diaphragm and shearwall design, p. 550R-3

Chapter 5—Structural integrity, p. 550R-3

Chapter 6—Member design, p. 550R-4

Chapter 7—Connection design, p. 550R-5

Chapter 8—Bearing design, p. 550R-6

Chapter 9—Items embedded after concrete placement, p. 550R-6

Chapter 10—Marking and identification, p. 550R-7

Chapter 11—Handling, p. 550R-7

Chapter 12—Strength evaluation of precast construction, p. 550R-7

Chapter 13—References, p. 550R-7

13.1—Recommended references

13.2—Cited references

CHAPTER 1—SCOPE

1.1

Recommendations of this report apply to design of precast concrete structures where all members or selected members are cast somewhere other than their final position in the structure.

1.2

This report should be used together with ACI 318, "Building Code Requirements for Reinforced Concrete," the minimum requirements of which may be legally binding. Because of the nature of precast concrete, certain recommendations contained in this report differ from the requirements of ACI 318.

1.3

Some of these recommendations may not be applicable to special conditions. Engineering judgment should be used in implementing this report.

1.3.1 Tilt-up concrete construction is a specialized type of

precast concrete construction. Because panel dimensions in tilt-up are generally much larger than those in plant-cast precast, and roof and floor diaphragms are generally not constructed with precast sections, certain recommendations in this report differ from common practice found in tilt-up concrete construction.

CHAPTER 2—GENERAL

2.1

In design of precast members and connections, all loading and restraint conditions from casting to end use of the structure should be considered. The stresses developed in precast elements during the period from casting to final connection may be more critical than the service load stresses. Special attention should be given to the methods of stripping, storing, transporting, and erecting precast elements.

2.2

When precast members are incorporated into a structural system, the forces and deformations occurring in and adjacent to connections (in adjoining members and in the entire structure) should be considered.

The structural behavior of precast elements may differ substantially from that of similar members that are monolithically cast in place. Design of connections to transmit forces due to shrinkage, creep, temperature change, elastic deformation, wind forces, and earthquake forces require special attention. Details of such connections are especially important to insure adequate performance of precast structures.

2.3

Precast members and connections should be designed to meet tolerance requirements. The behavior of precast members and connections is sensitive to tolerances. Design should provide for the effects of adverse combinations of fabrication and erection tolerances.

Tolerance requirements should be listed on contract documents, and may be specified by reference to accepted standards.¹⁻³ Tolerances that deviate from accepted standards should be so indicated.

2.4

All details of reinforcement, connections, bearing elements, inserts, anchors, concrete cover, openings and lifting devices, and specified strength of concrete at critical stages of fabrication and construction, should be shown on either the contract documents prepared by the architect/engineer of record or on the shop drawings furnished by the contractor. Whether this information is to be shown on the contract documents or shop drawings depends on the provisions of the contract documents. The shop drawings should show, as a minimum, all details of the precast concrete members and embedded items. The contract documents may specify that portions of connections exterior to the member are also to be shown on the shop drawings. The contract documents may also require the contractor to provide designs for the members and/or connections.

The contract documents should show the loads to be considered in design of the precast concrete elements of the structure, and they should indicate any special requirements or functions (for example: seismic loads, allowance for movements, etc.) that should be considered in design assigned to the contractor. In this case, the shop drawings should include complete details of the connections involved.

CHAPTER 3—DISTRIBUTION OF FORCES DUE TO GRAVITY LOADS

3.1

Design of precast floors with or without bonded concrete toppings that are subjected to concentrated or line loads may take into account distribution of forces. This distribution between hollow-core or solid slabs is well documented.⁴⁻⁷ It occurs even if no transverse moment strength exists across the joint, but shear continuity is maintained. Lateral distribution is made possible largely by the torsional stiffness of the members and the shear strength of the joint. Stemmed members with thin flanges have relatively low torsional stiffness and provide limited distribution.

3.2

The distribution of forces should be established by rational analysis or test. Distributions of deflections, moments, and shears are independent of each other, so one should not be inferred from any of the others.⁸ Extensive tests⁷ have shown that modes of failure in hollow-core slab systems can include longitudinal splitting due to transverse bending, punching shear, or joint shear in addition to member flexure and shear. Strengths in these modes depend on parameters such as material properties, cross-sectional geometry, and location of the load relative to voids and joints. Openings in the floor system can influence lateral distribution.

3.2.1 Many methods of analysis, such as the finite element method, orthotropic plate theory,⁹⁻¹⁰ the finite strip method,⁸ and others¹¹ are available. It is important to model the appropriate transverse moment continuity across the joints and, in some types of members, the vertical displacements due to transverse shear.

3.2.2 The *PCI Hollow Core Design Manual*¹² contains a method based largely on test results.

3.2.3 All of the preceding methods may be used to predict force distributions between members. Research is continuing in this area.

CHAPTER 4—DIAPHRAGM AND SHEARWALL DESIGN

4.1

Precast concrete members can be assembled and connected to produce a structural system capable of resisting in-plane forces that result from wind, earthquake, or other lateral loads. Hollow-core slabs, solid slabs, or stemmed members used as either deck members or wall panels may be used in such structural systems.

4.2

Complete integrity of the structural system, which may include diaphragms, shearwalls, and their connections, should be assured. This includes, but is not limited to, the following: connections to transfer in-plane forces into the system; flexural integrity including proper tension and compression elements, and any necessary internal connections; shear integrity including any necessary internal shear transfer connections; and proper connections to transfer in-plane forces out of the system.

4.3

Analysis of a diaphragm and shearwall system should include consideration of the diaphragm flexibility and the shearwall stiffnesses relative one to another. Diaphragm flexibility can affect the distribution of lateral forces to vertical elements and may also affect the general performance of the structure.

4.4

The *PCI Design Handbook*¹³ and the *PCI Hollow-Core Manual*¹² contain methods of analysis and design, and provide additional references.

CHAPTER 5—STRUCTURAL INTEGRITY

5.1

The structural integrity provisions of the *ACI Building Code* are intended to provide toughness that will increase a structure's likelihood of surviving abnormal loads or displacements. The overall integrity of a structure can often be substantially enhanced by minor changes in the amount, location, and detailing of member reinforcement and in the detailing of connections.

5.2

Integrity connections should not rely solely on friction caused by gravity loads. An exception could be heavy modular unit structures where resistance to overturning or sliding has a safety factor of 5 or more, or where sliding or rocking will not affect adversely the performance of the structure.

5.3

Integrity connections should be located to minimize the potential for cracking due to restraint of volume changes.

5.4

Integrity connections should be proportioned to develop a failure mode by yielding of steel.

5.5

Since the ACI 318 provisions for integrity of precast concrete structures are quite general, the following recommendations are provided to aid the designer in meeting the intent of those provisions. Since the design forces specified in these recommendations are chosen somewhat arbitrarily, it is not necessary to include a strength reduction factor in the calculations. These recommendations are minimums and all appli-