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Introduction to ACI/PCI 319-25 *Building Code Requirements for Structural Precast Concrete—Code and Commentary*

- This article introduces the new ACI/PCI 319 code, *Building Code Requirements for Structural Precast Concrete—Code and Commentary.*
- Developed jointly by the American Concrete Institute (ACI) and PCI, this document is based on existing concrete code requirements from *Building Code Requirements for Structural Concrete (ACI 318-19) and Commentary (ACI 318R-19).*
- It also includes additional design requirements developed by PCI specifically for structural precast concrete components and systems.

In 1936, the French engineer Eugène Freyssinet introduced prestressed concrete to a broad audience in London, England. Applying European knowledge and experience, Gustave Magnel designed the Walnut Lane Memorial Bridge in Philadelphia, Pa., in 1949. That structure represents the first U.S. example of using prestressed concrete as a viable solution. The Precast Concrete Institute Inc. was chartered just over 70 years ago on June 18, 1954, in Tampa, Fla. Months after its establishment, on October 7, 1954, PCI published *Specifications for Pretensioned Bonded Prestressed Concrete*.[1] The pursuit of prestressed concrete standards in the United States had begun. A more detailed history and the framework for nearly a half-century of code development between the American Concrete Institute (ACI) and PCI is presented in "Building Code Provisions for Precast/Prestressed Concrete: A Brief History."[2] As the authors of that *PCI Journal* article state, "At a meeting in Detroit in 1959, PCI negotiated an agreement with ACI in which ACI agreed to incorporate provisions for prestressed concrete into its code and to have four members from PCI on the ACI Code Committee to draft the code language." This agreement and subsequent collaborations have promoted the inclusion of the PCI body of knowledge in a larger arena and broadened the acceptance of precast and precast, prestressed concrete systems.

Between 1971 and 2011, ACI 318, *Building Code Requirements for Structural Concrete*,[3–5] addressed prestressed concrete in three chapters: "Precast Concrete," "Composite Concrete Flexural Members," and "Prestressed Concrete." The content in these chapters was overseen directly by ACI 318 Subcommittee G, and seismic considerations for precast concrete systems were addressed by Subcommittee H.

In 2014, ACI reorganized the code. Sparked by the decision to modernize the code's layout to more closely follow a practitioner's design process, ACI 318-14[6] was the first major format update to the code since 1971. In this reorganization, content from the three chapters specific to precast and precast, prestressed concrete was distributed throughout the body of the code. During the reorganization, Subcommittee G coordinated code-change proposals while remaining cognizant of proposals from other subcommittees that might have affected prestressed concrete. In the 2019 code cycle, more than 250 provisions, not including terminology and notation, across 26 chapters, underwent changes.[7] Since then, Subcommittee G transformed into separate subcommittees: Subcommittee P (Precast and Prestressed Concrete) and Subcommittee T (Post-tensioned Concrete); these subcommittees continue to monitor and initiate code-change proposals throughout ACI 318.

The first edition of the *PCI Design Handbook: Precast and Prestressed Concrete*[8] was published in 1971. The *PCI Design Handbook* has been the premier document for precast and prestressed concrete design methodology, and it has been used by academics and practicing engineers as the resource for current knowledge on precast concrete design. The ninth edition is expected to be published this year.

PCI first published "PCI Standard Design Practice" in 1997,[9] and the most recent update was published in 2021.[10] This document provides guidance on and, in some cases, exceptions to ACI 318 requirements as they apply to precast concrete.

PCI became an American National Standards Institute (ANSI) Standards Development Organization in 2014. With this accreditation, PCI began writing consensus standards relating to the design and detailing of precast concrete components and structures, two of which[11,12] are referenced by the *2024 International Building Code* (IBC).[13]

As the technical body of knowledge for the precast concrete industry expanded through robust research and development, PCI and other stakeholders in the industry grew concerned that recommendations to support the design practices in the *PCI Design Handbook* were not recognized to have standards authority. PCI began strategic planning for a PCI standards development path. Experts in the design, fabrication, and installation of precast concrete components and systems were engaged to provide guidance. In 2018, PCI approved a new strategic plan, with its first strategic goal being to "develop and maintain a precast, prestressed concrete design specification."[14] As an initial step toward meeting this goal, PCI's Technical Activities Council (TAC) established the Design Standard Committee under the leadership of Ned Cleland. Applying ANSI consensus-based standards-writing requirements, this committee focused on the development of new precast concrete design provisions based primarily on content from the *PCI Design Handbook* (then in its eighth edition[15]); the intention was to include these key provisions in a new precast concrete building code that would be referenced by the 2027 IBC.[14]

In March 2020, ACI and PCI assembled a joint committee to pursue the unified development of ACI/PCI 319, *Structural Precast Concrete—Code Requirements and Commentary*.[16] This joint committee was structured as a balanced code committee under the ACI Technical Activities Council, with leadership from Andrea Schokker, and its membership partially overlapped between the PCI Design Standard Committee and ACI 318 Subcommittee P. This arrangement facilitated a smooth workflow as new provisions were passed from PCI to the joint committee, and applicable ACI 318 content was reviewed for inclusion or reference in ACI/PCI 319.

PCI Design Standard Committee content developed for ACI/PCI 319

ACI/PCI 319 is a standalone codebook. Although it is published separately from ACI 318, it will include some content from ACI 318 and will reference provisions from ACI 318, among other standards.

The following nine items identified as needing codification were developed by the PCI Design Standard Committee and are included in ACI/PCI 319:

- torsion design
- corbel design
- dapped end beam design
- notched end beam design
- bearing regions
- intermediate precast concrete structural walls
- diaphragms with cast-in-place pour strips
- shear friction
- testing precast concrete connections, components, and erected structures

Torsion

The existing torsion provisions in ACI 318 were developed by considering relatively compact sections. In ACI/PCI 319, the provisions have been expanded to include two methods from the *PCI Design Handbook*. The first is based on the Zia and McGee procedure,[17] updated by Zia and Hsu,[18] which allows the benefits of prestressing strand on concrete contribution to be included. This method, referenced in ACI 318-19 commentary 9.5.4.6, allows an alternative design for solid sections with an aspect ratio h/b_t of 3 or greater, where h is the overall height of the member and b_t is the width of the section containing the closed stirrups related to torsion. The additions in ACI/PCI 319 provide requirements for meeting the intent of ACI 318-19 commentary 9.5.4.6 and include the determination of minimum reinforcement requirements instead of ACI 318-19 section 9.6.4. Detailing requirements of ACI 318-19 sections 9.7.5 and 9.7.6.3 are maintained in ACI/PCI 319 for this method.

The second method from the *PCI Design Handbook* is often referred to as the plate-bending method due to the skewed bending stresses seen in the end region of the thinner beam webs. This method is currently addressed in ACI 318-19 section 9.5.4.7 for slender spandrels, based on PCI-funded research by Lucier et al.,[19,20] where the aspect ratio $h/b_t \geq 4.5$. The complete requirements to satisfy the intent of the testing are now part of the body of the ACI/PCI 319 code, and the ACI/PCI 319 provisions related to this method include expanded detailing requirements and commentary. When this method is used, the minimum reinforcement requirements of ACI 318-19 section 9.6.4 and the detailing requirements of ACI 318-19 sections 9.7.5 and 9.7.6.3 need not be satisfied.

Corbels

While there are requirements for corbel design in ACI 318, the new ACI/PCI 319 provisions include consideration of corbel geometry, with an upper limit of $4a_v$, where a_v is shear span, on the effective corbel depth based on a realistic strain distribution. ACI/PCI 319 also uses updated shear friction provisions, including the PCI effective coefficient of shear friction design method. Bearing capacity that includes longitudinal force has been added as a required design check. Like ACI 318, ACI/PCI 319 permits the use of provisions from ACI 318 chapter 23 regardless of the shear span geometry.

Dapped beam ends

Dapped beam ends occur where the bearing portion of the component is recessed more than 0.2*h*, where *h* is total beam depth, or more than 8 in. in double tees, spandrels, and other types of beams, excluding slabs (**Fig. 1**). This type of geometry is often used to decrease the depth of the floor system in all types of construction. The *PCI Design Handbook* has provided step-by-step design examples since the 1970s. The configurations and procedures in ACI/PCI 319 are based on recent PCI-sponsored research[21,22] and are expressed as mandatory language. Special detailing is required based on potential failure modes and selected dap reinforcing and includes reinforcement for the following:

- flexural bending and axial restraint in the end
- shear in the section above the bearing and the interface between the reduced and full height of the section
- diagonal tension in the reentrant corner

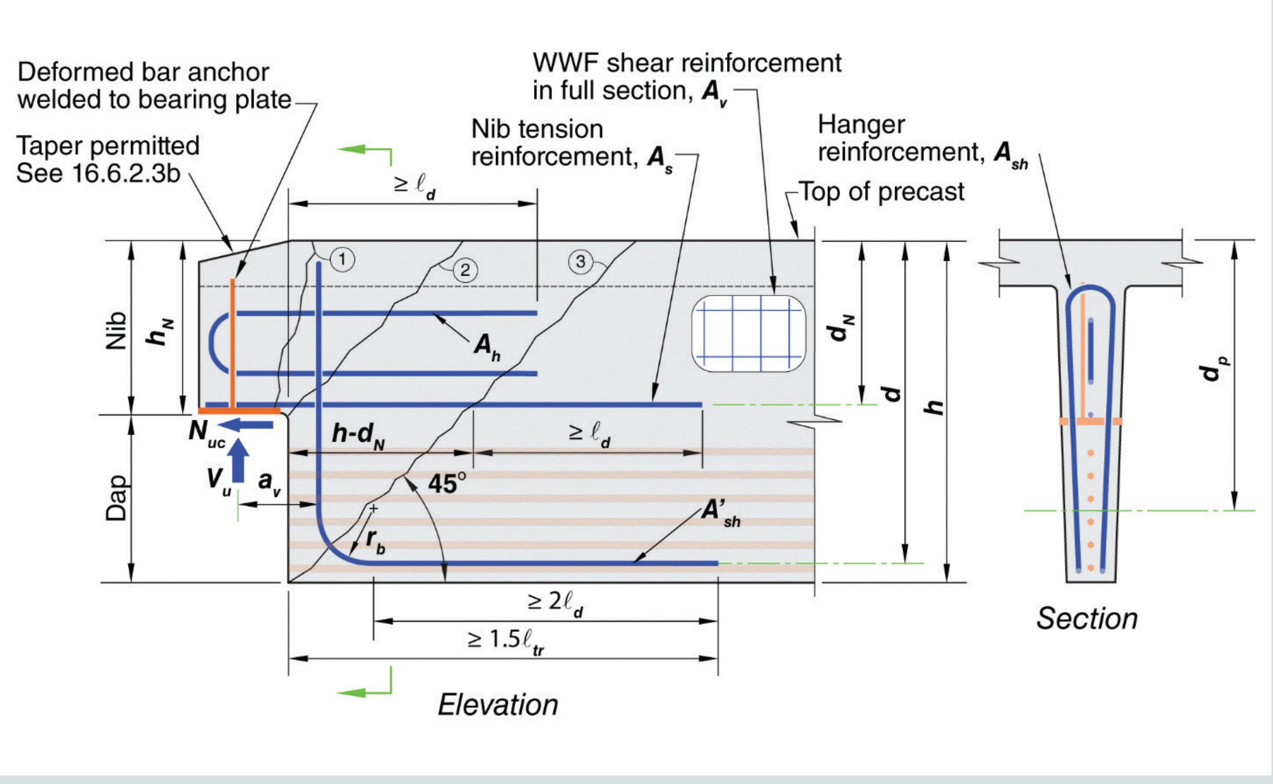

Figure 1. Example of a dapped end region. Reproduced from ACI/PCI 319. Note: Variables as defined in ACI/PCI 319.

- diagonal tension in the bottom corner of the full-height section
- reduced shear strength in the full-height section of the member within 2*h* of the dap face

Notched beam ends

Notched beam ends are a special case of dapped beam end design. Notches are essentially shallow daps limited to a dap height of less than 0.2*h* and less than 8 in. Although a notched beam end looks similar to a dapped beam end, the detailing requirements are substantively different. The new ACI/PCI 319 provisions include requirements for calculating the shear strength above the notch and moment equilibrium for reinforcement in the end region. Both notched and dapped end beam designs apply to thin-stemmed and non-thin-stemmed components as defined by the code.

Bearing regions

In ACI/PCI 319, section 16.8 addresses bearing regions of supporting and supported precast concrete components that are connected primarily by bearing. Where horizontal forces occur at the bearing end region, design strength and detailing requirements for these regions must be addressed. Consideration of moment equilibrium at the end region, consideration of the shear friction contribution, and guidance for nonuniform bearing are also included in section 16.8.

Intermediate precast concrete structural walls

Intermediate precast concrete structural walls are commonly used as part of the seismic-force-resisting systems of precast concrete buildings. In many cases, it is necessary to have walls that are of greater size or weight than can be manufactured, shipped, or installed in one piece. Panels of manageable size can be linked with discrete connections to perform as required under the design earthquake. Both strong and ductile connections are used to dictate the load path of lateral forces and the behavior of the overall system. ACI/PCI 319 expands section 18.5 from ACI 318-19 and adds new provisions that consider system implications of joints in intermediate precast concrete structural wall panels with strong connections as well as ductile connections. The ACI/PCI 319 provisions provide guidance for structural integrity and recognize that joints between panels may have connections with differing intended functions. More information on this kind of system detailing is found in PCI's *Seismic Design of Precast/Prestressed Concrete Structures* (MNL 140).[23]

Diaphragms with cast-in-place concrete pour strips

ACI 318-19 section 18.12.11 addresses diaphragms specific to precast concrete construction, with composite or noncomposite topping. That section of ACI 318 addresses precast concrete diaphragms only when there is a cast-in-place topping. The provisions in ACI/PCI 319 address diaphragms satisfying section 18.12.11.1 and constructed with cast-in-place pour strips at the ends of precast concrete floor or roof components and using mechanical connectors tested in accordance with ACI 550.4, *Qualification of Precast Concrete Diaphragm Connections and Reinforcement at Joints for Earthquake Loading and Commentary*,[24] that are distributed along the length of the joint. These provisions permit the design of the chord reinforcement to share part of the shear transfer. ACI/PCI 319's provisions require that at least half the shear be transferred along the length of the potential shear plane, similar to the existing provisions for topped diaphragms in ACI 318-19. ACI/PCI 319 includes the option to transfer as much as half the shear across a joint between floor members by shear friction in the chord. Commentary has been included in ACI/PCI 319 to clarify that moment on the shear plane does not add to the shear friction requirement because there is equilibrium of tension and compression in the diaphragm.

Shear friction

The effective coefficient of shear friction approach has been included in the *PCI Design Handbook* since the second edition, published in 1978.[25] The approach has since evolved through research and continued comparison with other methods. The new provisions in ACI/PCI 319 apply to monolithic and roughened construction joint interfaces not subjected to load reversal along the interface, including inclined shear planes. Additional limits on interface shear based on the interface condition, concrete strength, and area are provided. Requirements for detailing shear friction reinforcement for composite cast-in-place topping slabs, if used, are also included.

Existing structures

ACI/PCI 319 chapter 27, "Strength Evaluation of Existing Structures," includes section 27.7, which covers precast concrete connections, components, and erected structures. This new section does not apply to strength evaluation due to deterioration or periodic evaluation because those scenarios are addressed in sections of ACI 318 and in ACI 437, *Strength Evaluation of Existing Concrete Buildings*.[26] Instead, ACI/PCI 319 section 27.7 addresses cases where there is doubt as to the structural safety of a precast concrete component or partially erected precast concrete structure. The PCI Plant Certification Program requires plants to maintain documentation of compliance with MNL 116, *Manual for the Quality Control for Plants and Production of Structural Precast Concrete Products*;[27] MNL 117, *Manual for the Quality Control for Plants and Production of Architectural Precast Concrete Products*;[28] and MNL 130, *Manual for Quality Control for Plants and Production of Glass Fiber Reinforced Concrete Products*.[29] These records may be used to verify as-built conditions and allow for analytical strength evaluation or evaluation by testing, which facilitates determination regarding the acceptability of precast concrete components or the partially erected structure. The new provisions in ACI/PCI 319 give the baseline requirements for engineers to make informed decisions. The provisions also permit the testing of exemplar samples in qualified laboratories when design strengths are questioned. Time and material resources can be saved by applying this methodology.

Conclusion

The development of ACI/PCI 319, *Building Code Requirements for Structural Precast Concrete—Code and Commentary*, has been an immense undertaking by both PCI and ACI. Stakeholders showed a strong interest in the document during its development, and it is already apparent that there is more to address in future editions as work on ACI/PCI 319 continues in future code cycles.

Acknowledgments

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References

Much of the research data referenced in preparing ACI/PCI 319-25 is cited for the user desiring to study individual questions in greater detail. A few are highlighted in this reference list. Other documents that provide suggestions for carrying out the requirements of ACI/PCI 319-25 are also cited, including PCI standards.

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Abstract

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Keywords

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