Background and discussion of the *PCI Design Handbook: Precast and Prestressed Concrete*, ninth edition

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The Precast/Prestressed Concrete Institute (PCI) is the nonprofit technical institute and trade organization for the precast concrete structures industry in the United States. Since its founding in 1954, PCI has developed, maintained, and disseminated its body of knowledge to be widely used by the construction industry for the design, fabrication, and erection of precast concrete components and systems. To achieve this purpose, PCI continually disseminates information on the latest concepts, techniques, and design data to the engineering and architectural professions through regional and national programs and technical publications.

The *PCI Design Handbook: Precast and Prestressed Concrete* is the flagship publication for PCI and the premier resource for precast and prestressed concrete design. Architects, engineers, and educators use the handbook as a resource on precast concrete design, fabrication, and erection. Each edition of the *PCI Design Handbook* reflects updates to the relevant codes and standards, the most recent research completed on precast and prestressed concrete, current industry practice, and the experience of designers of precast and prestressed concrete structures.

Publication of the *PCI Design Handbook: Precast and Prestressed Concrete*, ninth edition,[1] continues to build on the purpose established with its first edition, published in 1971:[2] "The primary objective of this Handbook is to make it easier for architects and engineers to use prestressed and precast concrete. It is intended to be a working tool, assisting the designer in achieving optimum solutions in minimum time."

Purpose

The purpose of this background and discussion article is to identify and describe the significant changes of the *PCI Design Handbook: Precast and Prestressed Concrete*, ninth edition,[1] from the eighth edition. This is the eighth iteration of the background and discussion, each following publication of a newly updated handbook, starting with the second edition. Each prior article also appeared in the *PCI Journal*:

- For the second-edition *PCI Design Handbook*:[3] January–February 1980 issue[4]

- For the third-edition *PCI Design Handbook*:[5] May–June 1988 issue[6]
- For the fourth-edition *PCI Design Handbook*:[7] November–December 1996 issue[8]
- For the fifth-edition *PCI Design Handbook*:[9] July–August 1998 issue[10]
- For the sixth-edition *PCI Design Handbook*:[11] March–April 2006 issue[12]
- For the seventh-edition *PCI Design Handbook*:[13] Fall 2010 issue[14]
- For the eighth-edition *PCI Design Handbook*:[15] November–December 2018 issue[16]

These papers are available on the *PCI Journal* website at https://www.pci.org/PCI-Journal.

Process

The development of each of the handbook's chapters involved a rigorous process led by industry subject matter experts supported by an editorial and publication team. For the inaugural ninth-edition committee meeting on February 21, 2018, the roster included 34 voting members and 11 consulting members. Subcommittees of voting and consulting members led the development of each chapter. At the time of publication, in 2025, the roster included 26 voting members, 12 consulting members, and 19 Blue Ribbon Review Committee members.

Each chapter was updated from the eighth edition to incorporate errata and was reformatted to place examples at the end. The subcommittee for each chapter reviewed recommendations from the eighth edition that were not included in the previous edition. Each subcommittee completed the general updates discussed in the following section to develop a chapter representing the current state-of-the-practice. In addition, the committee conducted over 40 letter ballots to finalize the content of each chapter.

After the committee process was complete, technical editors reviewed each chapter for consistency and style. Subsequently, the PCI Technical Activities Council (TAC) reviewed and balloted each chapter. After each chapter was updated following the TAC review, the Blue Ribbon Review Committee, consisting of additional industry experts with a fresh perspective, performed a final review.

General updates

The ninth edition of the *PCI Design Handbook* remains consistent with the eighth edition in many ways. The overall updates and modifications generally fall into one of the following categories:

- updates to the referenced codes and standards, including:
  - 2015 *International Building Code* (IBC)[17] updated to 2021 IBC[18]
  - American Concrete Institute's (ACI's) *Building Code Requirements for Structural Concrete (ACI 318-14) and Commentary (ACI 318R-14)*[19] updated to ACI CODE-318-19[20]
  - American Society of Civil Engineers' (ASCE's) *Minimum Design Loads for Buildings and Other Structures (ASCE 7-10)*[21] updated to ASCE's *Minimum Design Loads and Associated Criteria for Buildings and Other Structures* (ASCE 7-16)[22]
- updates to current standard practices of the industry, including common component sizes and connection detailing practices
- updates from the results of recent research, primarily research sponsored by the Research and Development Council of PCI
- expanded discussion of selected topics for a more comprehensive discussion
- replacement of chapter 13, "Tolerances for Precast and Prestressed Concrete" with "Design for Extreme Events"
- deletion of three appendices: blast-resistant design, structural integrity and disproportionate collapse, and seismic design of diaphragms; these appendices have been incorporated into the handbook's chapters as appropriate and have not been retained in the ninth edition

Table 1 outlines the chapter organization changes from the eighth edition to the ninth edition of the *PCI Design Handbook*. The revision of some titles from "Precast/Prestressed Concrete" to "Precast Concrete" reflects updated industry terminology. Precast concrete refers to plant-cast, prefabricated concrete components and includes both precast, nonprestressed components and precast, prestressed components. Precast/Prestressed is mostly reserved for Precast/Prestressed Concrete Institute.

Two significant stylistic changes were made that previous handbook users will notice:

- Reference citations within the text are updated to an author-date style from the prior reference-number style (for example, "(Mast 2001)" from "Mast[2]"). Accordingly, the reference list at the end of each chapter is now alphabetical. This change will greatly simplify future editions if a new reference is added early in a chapter, rather than requiring each subsequent reference number to be changed.
- All examples are now placed at the end of the chapter, before the design aids, rather than placed within the text. Along with this change, a list of all examples is included at the end of the table of contents for each chapter. This

Table 1. Chapter comparison for eighth-edition and ninth-edition *PCI Design Handbook*		
	Eighth edition	**Ninth edition**
Chapter 1	Precast and Prestressed Concrete: Applications	Precast and Prestressed Concrete: Overview
Chapter 2	Notations	Notations
Chapter 3	Preliminary Design of Precast/Prestressed Concrete Components	Preliminary Design of Precast Concrete Components
Chapter 4	Analysis and Design of Precast/Prestressed Concrete Structures	Analysis and Design of Precast Concrete Structures
Chapter 5	Design of Precast and Prestressed Concrete Components	Design of Precast and Prestressed Concrete Components
Chapter 6	Design of Connections	Design of Connections
Chapter 7	Structural Considerations for Architectural Precast Concrete	Structural Considerations for Architectural Precast Concrete
Chapter 8	Component Handling and Erection Bracing	Component Handling and Erection Bracing
Chapter 9	Precast and Prestressed Concrete: Materials	Materials and Production
Chapter 10	Design for Fire Resistance of Precast and Prestressed Concrete	Design for Fire Resistance of Precast and Prestressed Concrete
Chapter 11	Thermal and Acoustical Properties of Precast Concrete	Thermal and Acoustical Properties of Precast Concrete
Chapter 12	Vibration Design of Precast/Prestressed Concrete Floor Systems	Vibration Design of Precast Concrete Floor Systems
Chapter 13	Tolerances for Precast and Prestressed Concrete	[Tolerances not included]
	[See appendixes plus added material]	Design for Extreme Events
Chapter 14	Specifications and Standard Practices	Standard Practices
Chapter 15	General Design Information	Reference Information
Appendix A	Blast-Resistant Design of Precast, Prestressed Concrete Components	[Material incorporated into section 13.2]
Appendix B	Design for Structural Integrity and Disproportionate Collapse	[Material incorporated into section 13.3]
Appendix C	Precast Concrete Diaphragm Design in Accordance with Alternative Provisions of ASCE/SEI 7-16	[Material incorporated into section 4.8]

change was used to facilitate consolidation of multistep examples into a comprehensive example and to simplify the chapter layout process.

The following sections summarize the chapter content and significant changes from the eighth edition. Additional discussion on changes is provided in the foreword to the handbook.

Chapter 1—Precast and Prestressed Concrete: Overview

Chapter 1 provides a general overview of the many applications of precast and prestressed concrete used in buildings and other structures.

This chapter was reorganized to introduce precast concrete and its common components and systems, demonstrate specific precast concrete applications for buildings and commercial projects, discuss the production process for precast concrete, and highlight research and development sponsored by PCI.

The chapter includes photographs from many outstanding projects submitted to the PCI Design Awards program, along with photographs from PCI producer members and other sources to highlight the possibilities that can be achieved with precast concrete.

A new section on unique applications has been added to demonstrate the versatility of precast and prestressed concrete. **Figures 1** and **2** are two example applications of precast concrete included in this section.

Another new section describes research and development sponsored by PCI to demonstrate over 50 years of investment that

Figure 1. Precast concrete piles and flower pots solved construction and durability issues for both the contractor and owner of this coastal park structure. Source: Reproduced from *PCI Design Handbook: Precast and Prestressed Concrete*, ninth edition (Fig. 1.2.56).

Figure 2. Architectural students designed this complex, ultra-high-performance concrete prototype shelter using precast concrete components. Source: Reproduced from *PCI Design Handbook: Precast and Prestressed Concrete*, ninth edition (Fig. 1.2.57).

PCI has made to advance the industry and improve the design, manufacture, and construction of precast concrete components and structures.

Chapter 2—Notations

Chapter 2 contains the notations for the entire handbook and, as was the case in the eighth edition, is organized by chapter of the handbook. In general, the notation included in chapter 2 has been used within text, equations, tables, and figures of the respective chapter as typical notation. Occasionally, an example uses a specific notation that is not used elsewhere; in this case, the notation has not been added to chapter 2. Where notation from ACI CODE-318-19[20] is used, it is identified with "(ACI)."

Due to the breadth of topics covered in the handbook, there are cases where the same notation is used for different applications. For example, "R = response modification coefficient (see section 4.2.4 and design aid 4-9)" and "R = cumulative load effect of service rain load (ACI) (see section 4.2.6)." This duplication is minimized where possible and is typically used only in different chapters. Where duplication exists within a chapter, the specific section identification for each definition has been included as shown.

The committee considered developing a precast concrete terminology section; however, because terminology use varies depending on application, a consolidated terminology section is not included. The committee found it more user friendly to include application-specific definitions either at the beginning of the chapter or in the text where the terminology is used.

Chapter 3—Preliminary Design of Precast Concrete Components

Chapter 3 contains tables with generic component sections, which can be used for preliminary design to select component sizes based on the applied loading and required span length.

The chapter was updated to provide additional explanation about the preliminary load tables and limitations on their use. To reflect updated reference standards, the committee performed analyses for all section types and updated the corresponding load table values. **Figure 3** provides an example comparison between the eighth and ninth editions for a 12 ft wide, 30 in. deep double-tee (12DT30). For the 12DT30, the superimposed service load capacity increases for some combinations of span length and strand patterns but decreases for others. Additionally, the conditions in which concrete strength at prestress transfer controls the design, shown as shaded regions, have also changed. The chapter has maintained the same double-tee sections as the eighth edition.

Preliminary design tables for hollow-core components were retained and updated; however, the tables with proprietary hollow-core section properties found in previous editions have been deleted, as this information is available in PCI's *Manual for the Design of Hollow Core Slabs and Walls* (PCI MNL-126-15)[23] and was not used otherwise in the handbook.

New preliminary design tables for 10 in. thick and 12 in. thick solid flat slabs have been added, both with no topping and with a 2 in. composite normalweight topping.

Similar to the preliminary design tables, the committee reviewed and updated the design aids in accordance with the reference standards. **Figure 4** shows a comparison of the relevant strengths to construct the interaction curves for precast, prestressed solid and insulated concrete wall panels.

Design aid 3-9, "Recommended Maximum Spans for Precast Concrete Stairs," has been updated to include achievable span lengths when compression reinforcement is used.

Eighth-edition table for 12DT30

12DT30

Table of superimposed service load capacity, lb/ft², and cambers, in.

Normalweight—no topping

Strand pattern	y_s (end) y_s (center), in.	Span, ft																					
		40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82
128-S	7.00	158	138	120	105	91	79	69	59	51	43	37	30										
	7.00	0.8	0.8	0.9	0.9	0.9	0.9	0.8	0.8	0.7	0.6	0.5	0.4										
		1.1	1.2	1.2	1.2	1.2	1.2	1.1	1.1	1.0	0.8	0.6	0.4										
148-S	8.00	182	160	140	123	108	95	83	73	63	55	47	41	34	29								
	8.00	0.9	1.0	1.0	1.0	1.0	1.1	1.0	1.0	1.0	0.9	0.8	0.7	0.5	0.3								
		1.3	1.3	1.4	1.4	1.4	1.5	1.4	1.4	1.3	1.2	1.0	0.9	0.6	0.4								
168-S	9.00		178	157	139	122	108	95	84	74	65	57	49	42	36	31							
	9.00		1.1	1.1	1.2	1.2	1.2	1.2	1.2	1.1	1.1	1.0	0.9	0.8	0.6	0.4							
			1.5	1.5	1.6	1.6	1.6	1.6	1.6	1.6	1.5	1.3	1.2	0.0	0.7	0.4							
188-S	10.00		194	171	152	134	119	106	93	83	73	64	56	49	43	36	29						
	10.00		1.1	1.2	1.2	1.3	1.3	1.3	1.3	1.3	1.2	1.1	1.0	0.9	0.8	0.6	0.4						
			1.6	1.6	1.7	1.7	1.8	1.8	1.8	1.7	1.7	1.6	1.4	1.2	1.0	0.7	0.4						
188-D1	14.39					184	165	148	132	119	107	96	86	77	68	61	54	48	42	35	29		
	4.00					1.6	1.7	1.7	1.8	1.8	1.8	1.8	1.7	1.7	1.6	1.4	1.3	1.1	0.9	0.6	0.3		
						2.2	2.3	2.4	2.4	2.4	2.4	2.3	2.2	2.1	2.0	1.9	1.7	1.4	1.1	0.7	0.2		
208-D1	15.50							166	149	135	121	109	97	86	76	68	61	54	48	43	37	31	26
	4.25							1.9	2.0	2.0	2.0	2.1	2.1	2.0	1.9	1.8	1.7	1.5	1.3	1.1	0.8	0.5	0.1
								2.6	2.7	2.7	2.7	2.7	2.7	2.6	2.4	2.3	2.1	1.9	1.7	1.4	1.0	0.5	–0.1

Ninth-edition table for 12DT30

12DT30

Table of superimposed service load capacity, lb/ft², and cambers, in.

Normalweight—no topping

Strand pattern	y_s (end) y_s (center), in.	Span, ft																				
		40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80
128-S	7.00	162	142	124	109	95	84	73	64	55	48	41	35	29								
	7.00	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.8	0.8	0.7	0.6	0.5								
		1.0	1.0	1.0	1.1	1.1	1.0	1.0	1.0	0.9	0.8	0.7	0.5	0.3								
148-S	8.00	186	164	144	127	112	99	87	77	68	59	52	45	39	33							
	8.00	0.9	1.0	1.0	1.1	1.1	1.1	1.1	1.1	1.1	1.0	1.0	0.9	0.8	0.6							
		1.1	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.1	1.1	1.0	0.8	0.7	0.5							
168-S	9.00		183	161	143	127	112	100	88	78	69	61	53	47	41	35	30					
	9.00		1.1	1.1	1.2	1.2	1.2	1.3	1.2	1.2	1.2	1.1	1.1	1.0	0.8	0.7	0.5					
			1.3	1.3	1.4	1.4	1.4	1.4	1.4	1.3	1.3	1.2	1.1	0.9	0.7	0.5	0.3					
188-S	10.00		198	176	156	139	123	110	98	87	77	69	61	53	47	41	35	30				
	10.00		1.1	1.2	1.3	1.3	1.3	1.3	1.4	1.3	1.3	1.3	1.2	1.1	1.0	0.9	0.7	0.5				
			1.3	1.4	1.5	1.5	1.5	1.5	1.5	1.5	1.4	1.3	1.2	1.1	0.9	0.7	0.5	0.2				
188-D1	14.39						151	135	120	108	96	86	76	68	60	53	46	40	35	30		
	4.00						1.5	1.5	1.6	1.6	1.6	1.6	1.5	1.5	1.4	1.3	1.1	0.9	0.7	0.5		
							1.7	1.8	1.8	1.8	1.8	1.7	1.6	1.5	1.4	1.2	1.0	0.8	0.5	0.1		
208-D1	15.50									114	102	92	82	73	65	58	51	45	39	34	29	25
	4.25									1.8	1.8	1.8	1.8	1.7	1.6	1.5	1.4	1.3	1.1	0.9	0.6	0.3
										2.0	2.0	2.0	1.9	1.8	1.7	1.6	1.4	1.1	0.9	0.6	0.2	–0.2

Figure 3. Comparison of preliminary design tables for 12DT30.
Source: Reproduced from *PCI Design Handbook: Precast and Prestressed Concrete*, eighth edition, and *PCI Design Handbook: Precast and Prestressed Concrete*, ninth edition.

Chapter 4—Analysis and Design of Precast Concrete Structures

Chapter 4 addresses the precast concrete structural system, including structural loads and design for structural integrity and accommodation of volume changes. As most of the discussion relates to lateral-force-resisting systems for wind and seismic loads, there is discussion of precast concrete shear wall systems, moment-resisting building frame systems, and diaphragms.

While the overall section order remained the same as the eighth edition, the committee reorganized the content within most sections substantially to reduce duplication and improve clarity. The eighth edition included maps for ground snow loads and basic wind speeds that were duplicated from ASCE 7-10.[21] These maps were removed in the ninth edition because design values are available through the ASCE Hazard Tool website.

Section 4.5, Shear Wall Systems, includes significant revisions and new guidance. **Figure 5** (ninth-edition Fig. 4.5.4) was added to illustrate the relative contribution of shear or flexural deformations based on a wall's height-to-length ratio. The committee revised and clarified the distribution of lateral loads based on the relative stiffness of individual walls both parallel

Eighth-edition design aid 3.13.4

	Full interaction curve data						
		Partially developed strand force			Fully developed strand force		
***t*, in.**	ϕP_o	ϕP_{nb}	ϕM_{nb}	ϕM_c	ϕP_{nb}	ϕM_{nb}	ϕM_c
4	129	46	5.3	0.9	22	4	2.2
6	194	69	11.9	2.0	33	9	5.0
8	259	92	21.2	3.6	45	16	9.0
10	323	115	33	5.6	56	25	14.0

Units for ϕP are kip, units for ϕM are kip-ft.

Values are for 1 ft width.

See Chapter 5 for definitions of partially developed and fully developed strand.

Ninth-edition design aid 3-4

	Full interaction curve data						
		Partially developed strand force			Fully developed strand force		
***t*, in.**	ϕP_o	ϕP_{nb}	ϕM_{nb}	ϕM_c	ϕP_{nb}	ϕM_{nb}	ϕM_c
4	129	25	4.0	1.1	22	4	2.5
6	194	37	9.1	2.6	32	9.1	5.9
8	258	49	16.1	4.7	43	16	10.5
10	323	62	25.2	7.1	55	25	15.9

Units for ϕP are kip, units for ϕM are kip-ft; values are for 1 ft width.

See Chapter 5 for definitions of partially developed and fully developed strand.

If wall panels are wider than 12 ft or are mechanically connected to cause restraint in the transverse direction, multiply the values read from the charts by 0.85

Figure 4. Comparison of interaction curve data for solid and insulated wall panels.
Source: Reproduced from *PCI Design Handbook: Precast and Prestressed Concrete*, eighth edition, and *PCI Design Handbook: Precast and Prestressed Concrete*, ninth edition.

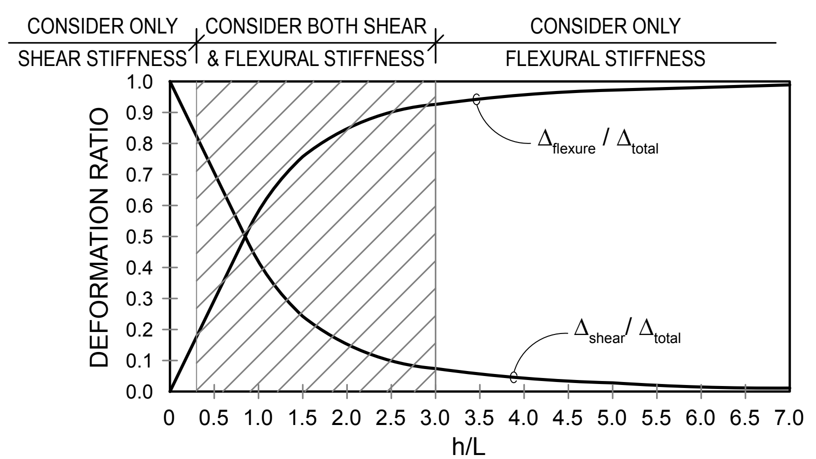


Figure 5. Relative contribution of shear and flexural deformations to total deformations of a cantilever shear wall. Source: Reproduced from *PCI Design Handbook: Precast and Prestressed Concrete*, ninth edition (Fig. 4.5.4).

and perpendicular to the direction of analysis. A new flowchart, **Fig. 6** (ninth-edition Fig. 4.5.6), guides the design of wall special boundary elements. Similarly, a new flowchart for ordinary, intermediate, or special precast concrete shear walls with openings guides the design of vertical wall segments as a column or a pier in accordance with requirements in ACI CODE-318-19,[20] chapter 18.

The committee revised section 4.6, Moment-Resisting Building Frames, to reduce content on moment resistance of column bases and refer to the relevant *PCI Journal* articles available on the PCI website.

In the eighth edition, appendix C discussed the diaphragm seismic design methodology from ASCE 7-16,[22] section 12.10.3. The ninth edition incorporates this content into section 4.8, along with updates and references to ACI CODE-550.4-18[24] and ACI CODE-550.5-18,[25] as referenced by ACI CODE-318-19.[20] The section on diaphragm design includes expanded discussion of analysis methods and a new discussion and flowchart to determine when ASCE 7-16,[22] section 12.10.1 (traditional method), or ASCE 7-16, section 12.10.3 (Diaphragm Seismic Design Methodology [DSDM]), diaphragm forces apply. As a precursor to future codes, and to provide clarification, the discussion also includes diaphragm types and classifications defined in ASCE 7-22.[26]

Section 4.9 is new; it provides information and guidance on the use of finite element modeling in precast concrete structures.

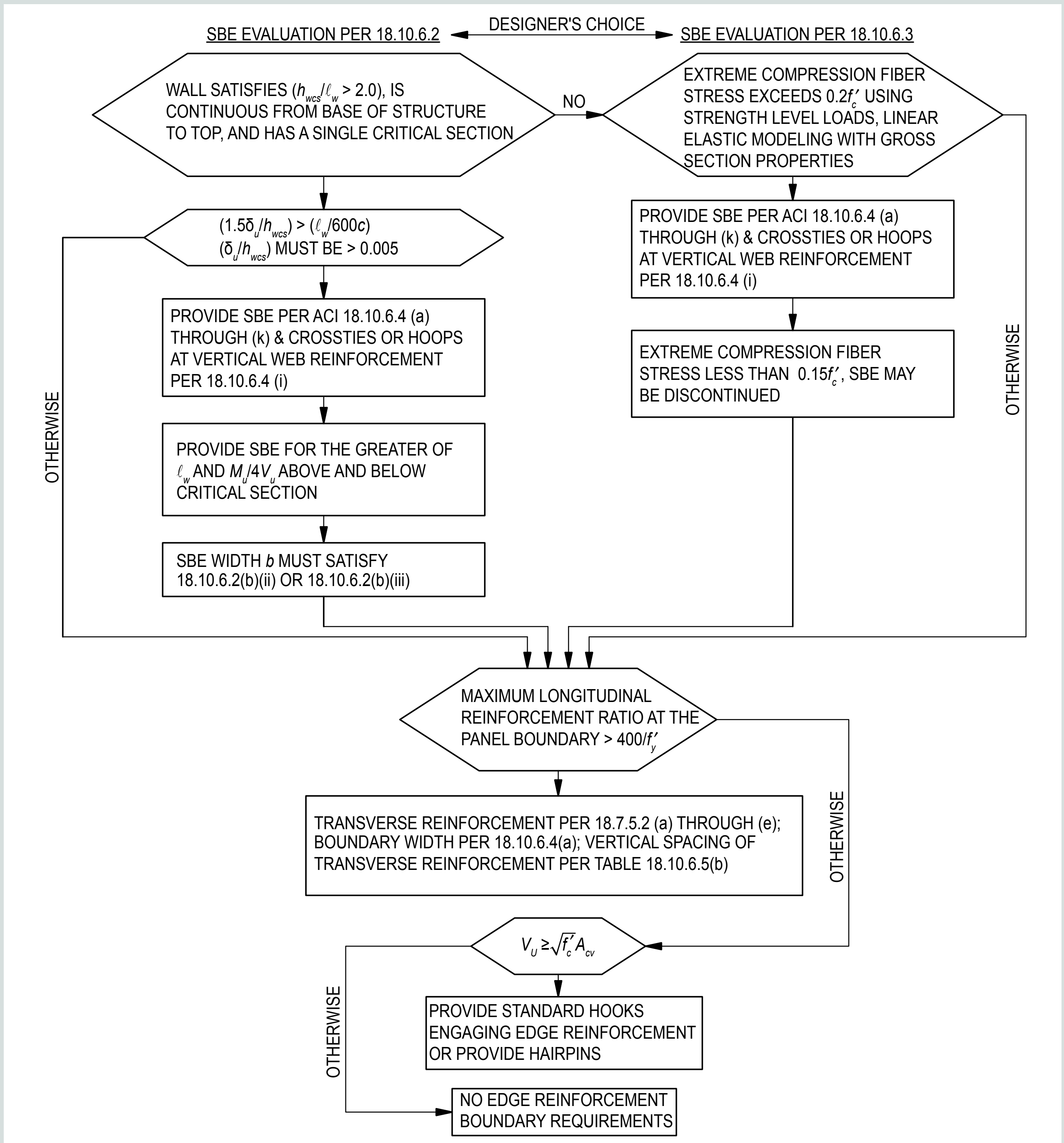


Figure 6. Flowchart to aid in the design of special boundary elements. Source: Reproduced from *PCI Design Handbook: Precast and Prestressed Concrete*, ninth edition (Fig. 4.5.6).

The committee reviewed each example thoroughly and provided expanded calculations for additional clarity. It retained and expanded the five-level parking structure from the eighth edition and included analysis of the lateral-force-resisting shear walls and the diaphragm.

Additional examples on diaphragm design are being developed and will be provided on the PCI Bookstore page for the ninth edition of the *PCI Design Handbook* when available.

Chapter 5—Design of Precast and Prestressed Concrete Components

Chapter 5 addresses the design of precast concrete components. While developing the ninth edition of the *PCI Design Handbook*, the PCI Design Standard Committee was also developing provisions for ACI/PCI CODE-319-25,[27] *Structural Precast Concrete—Code Requirements and Commentary*. The ninth-edition handbook does not refer to this new standard, but the committee updated the design guidance in several sections of this chapter to align with the provisions developed by the PCI Design Standard Committee.

The chapter maintains an organization consistent with that of the eighth edition, albeit with revisions in most sections to align with changes in ACI CODE-318-19;[20] these include updates to the section on shear, such as new one-way shear equations for nonprestressed components, and the design of corbels using strut-and-tie methods. For additional discussion of significant changes in ACI CODE-318-19,[20] see the article in *PCI Journal*, "The Most Notable Changes from ACI 318-14 to ACI 318-19 for Precast Concrete."[28]

Figure 7 (ninth-edition Fig. 5.5.3) was added to guide the selection of the appropriate design procedure for components with end recesses.

To align with the provisions developed for ACI/PCI 319-25,[27] the ninth edition includes updated sections on dapped-end bearings and notches. For dapped-end bearings in thin-stemmed components, the eighth edition recommended that the extended end (nib) be proportioned such that

$\phi V_n \leq \phi 5\lambda\sqrt{f'_c} b_n d$ for the vertical C-shaped configuration and

$\phi V_n \leq \phi 6\lambda\sqrt{f'_c} b_n d$ for all other thin-stemmed configurations

where

ϕ = strength reduction factor

V_n = nominal nib shear strength

λ = modification factor to reflect the reduced mechanical properties of lightweight concrete relative to normalweight concrete of the same compressive strength

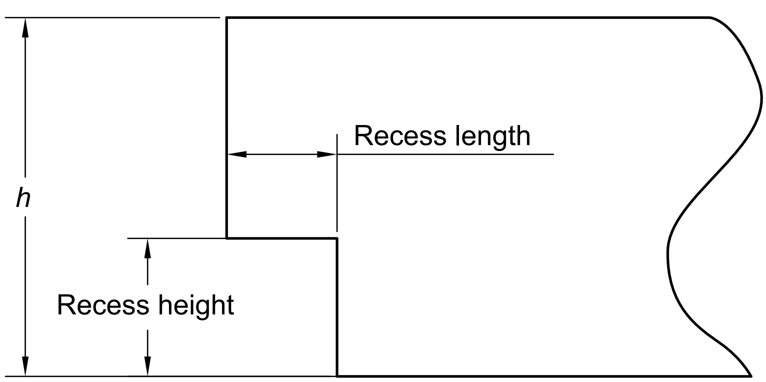
f'_c = specified compressive strength of concrete

$b_n d$ = average area of the nib

Table 2 is new to the ninth edition; it provides increased strengths for certain configurations for thin-stemmed components and addresses components with traditional transverse hanger stirrups. In addition, the eighth edition limited the concrete and steel contributions to shear strength for the full height section within $2H$ of the dap, where H is the overall depth of the component. The ninth edition also includes **Table 3** to provide additional clarity and detail for the strengths in this region.

For notched ends, the published and printed eighth-edition handbook did not include any requirements; however, errata (available at https://www.pci.org/PublicationErrata) added the new section 5.5.3.7, Notches. The ninth edition has revised the design methodology for notched ends and now includes a design model for moment equilibrium of a notched end region. This new methodology supersedes previous alerts and guidance issued by PCI. See section 5.5.4 for discussion of slabs with notches.

Section 5.6, on ledges, is generally unchanged from the eighth edition, except for ledges supporting continuous loads, which



Recess height limits	Design procedure
Recess height > 0.5*h*	Use Cazaly (section 6.9.1 of this handbook), Loov (section 6.9.2), or similar hanger design that satisfies the requirements of ACI 318.
min(0.2*h*, 8 in.) < Recess height ≤ 0.5*h*	Use dapped-end bearing design (section 5.5.3).
1.5 in. < Recess height ≤ min(0.2*h*, 8 in.)	Use notched-end bearing design (section 5.5.4).
Recess height ≤ min(1.5 in., 0.2*h*)	If plain concrete bearing design (section 5.5.1) is not satisfied, use reinforced bearing design (section 5.5.2).

Figure 7. Design procedure selection based on recess height.
Source: Reproduced from *PCI Design Handbook: Precast and Prestressed Concrete*, ninth edition (Fig. 5.5.3).

Table 2. Nib shear strength

Table 5.5.1. Nib shear strength V_n

Hanger reinforcement configuration	Maximum allowable V_n	
C-shaped hanger bar (C)[a]	$5\lambda\sqrt{f'_c}b_N d_N$	
Vertical C+Z hanger bars (CZ) **Vertical L hanger bar (VL)** **Inclined L hanger bar (IL)** **Welded-wire reinforcement (WWR)**	$6\lambda\sqrt{f'_c}b_N d_N$	
Vertical Z hanger bar (VZ)[b]	$7\lambda\sqrt{f'_c}b_N d_N$	
Transverse hanger stirrups[c,d]	Lesser of	$\dfrac{5}{\left(\dfrac{a_v}{d_N}\right)}\lambda\sqrt{f'_c}b_N d_N$
		$8\lambda\sqrt{f'_c}b_N d_N$

[a] C bar scheme where the top leg is turned away from the dap.

[b] As can be determined by examination of data from Nanni and Huang (2002).

[c] Should include an equivalent area of steel A'_{sh} that laps the longitudinal flexural steel and is adequately anchored at the face of the dap.

[d] This equation is based partially on Klein et al. (2019), while the upper bound of $8\lambda\sqrt{f'_c}b_N d_N$ is based on engineering judgment and only applies to low ratios of shear span to depth.

Source: Reproduced from *PCI Design Handbook: Precast and Prestressed Concrete*, ninth edition (Table 5.5.1).

were updated to align with changes made for ledges supporting concentrated loads to include the coefficient of shear strength β related to the supporting component demand-to-capacity ratio for shear and moment.

For analyzing corbels using the strut-and-tie method, ACI CODE-318-19,[20] section 23.5, was modified from ACI 318-14 to require minimum distributed reinforcement across the axes of interior struts. **Figure 8** shows the figures from both the eighth and ninth editions to demonstrate the resulting design based on this requirement for distributed reinforcement. Consequently, section 5.7.2 and example 5-6 in the ninth edition have been revised to reflect these and other updates introduced by ACI CODE-318-19[20] regarding the design and detailing of corbels using the strut-and-tie method.

In section 5.8.4 of the seventh-edition handbook, an equation was provided (Eq. [5-80]) to reduce the approximate long-term deflection multipliers when nonprestressed reinforcement was added. The eighth-edition committee removed this equation and referred to a *PCI Journal* paper[29] for more complete discussion on the methodology to reduce the multipliers. Section 5.9.4 of the ninth edition reintroduces this methodology and equations, with new limitations and clarifications for applicability, where there is nonprestressed reinforcement on the compression side of the components (that is, on the bottom side when the multiplier is for camber or on the top side when the multiplier is for deflection).

The ninth-edition includes the new section 5.13.8, Stair Design, along with example 5-18 for stair design using a horizontal span. **Table 4** is an aid for determining the self-weight of stair components including treads.

New, comprehensive design examples for different component types include double tees, inverted tees, and spandrel beams. Given the new comprehensive examples, the committee removed some redundant examples. These additional examples will be provided on the PCI Bookstore page for the ninth edition of the *PCI Design Handbook* when available.

Chapter 6—Design of Connections

This chapter discusses the design of connections, and as noted in its introduction, the design of connections is one of the most important considerations in the structural design of a precast concrete structure. As with prior editions of the handbook, a significant portion of this chapter addresses headed stud anchors with a design approach based on PCI-sponsored research that differs somewhat from ACI CODE-318-19[20] chapter 17, "Anchorage to Concrete," provisions primarily based on post-installed anchor tests.

Table 3. Full section shear strength in end region of dapped beams

Table 5.5.2. Full section shear strength in end region of dapped beams

Reinforcement scheme	Number of fully pretensioned and bonded strands (≥0.5 in. diameter) entering the nib	Concrete contribution to shear strength V_c	Maximum reinforcement contribution to shear strength V_s
Hanger reinforcement bent in the plane of the stem or web	0	$2\sqrt{f'_c}b_w d$	$2\sqrt{f'_c}b_w d$
	1[a]	$2.5\lambda\sqrt{f'_c}b_w d_p$	$2\sqrt{f'_c}b_w d_p$
	2 or more	$3\lambda\sqrt{f'_c}b_w d_p$	$2\sqrt{f'_c}b_w d_p$
Stirrup hanger reinforcement transverse to the plane of the web[b]	0[c]	$1.5\lambda\sqrt{f'_c}b_w d$	$3\sqrt{f'_c}b_w d$
	1 or fewer than 20% of strands[d]	$2.5\lambda\sqrt{f'_c}b_w d_p$	$3\sqrt{f'_c}b_w d_p$
	2 or more, and more than 20% of strands[d]	$3\lambda\sqrt{f'_c}b_w d_p$	$3\sqrt{f'_c}b_w d_p$

Note: The equations in the third and fourth columns are largely based on Botros et al. (2017) and Klein et al. (2019).

[a] While tests were performed on thin-stemmed components with zero or two strands, it is reasonable to assume a 2.5 multiplier for components with only one strand in the nib.

[b] Tests performed in Botros et al. (2017) did not include hanger stirrups (stirrups enclosing the longitudinal reinforcement as shown in Fig. 5.5.4[a]), but it is reasonable to assume specimens with hanger stirrups will behave similarly to those specimens that were tested. Because the stem is supported near middepth, the dapped connection induces additional diagonal tension stresses into the web. This behavior is described in Mattock and Theryo (1986).

[c] The lower concrete contribution to shear strength is based on testing of dapped ends of nonprestressed components with stirrup hanger and shear reinforcement (Peng 2009).

[d] The limit of one or two strands should be applied to thin-stemmed components, whereas the limit of 20% of strands should be applied to non-thin-stemmed components. Because an absolute number of prestressed strands is not always a proper metric for conventional dapped components, especially wider beams, 20% of strand in conventional beams was considered comparable to two strands in thin-stemmed components.

Source: Reproduced from *PCI Design Handbook: Precast and Prestressed Concrete*, ninth edition (Table 5.5.2).

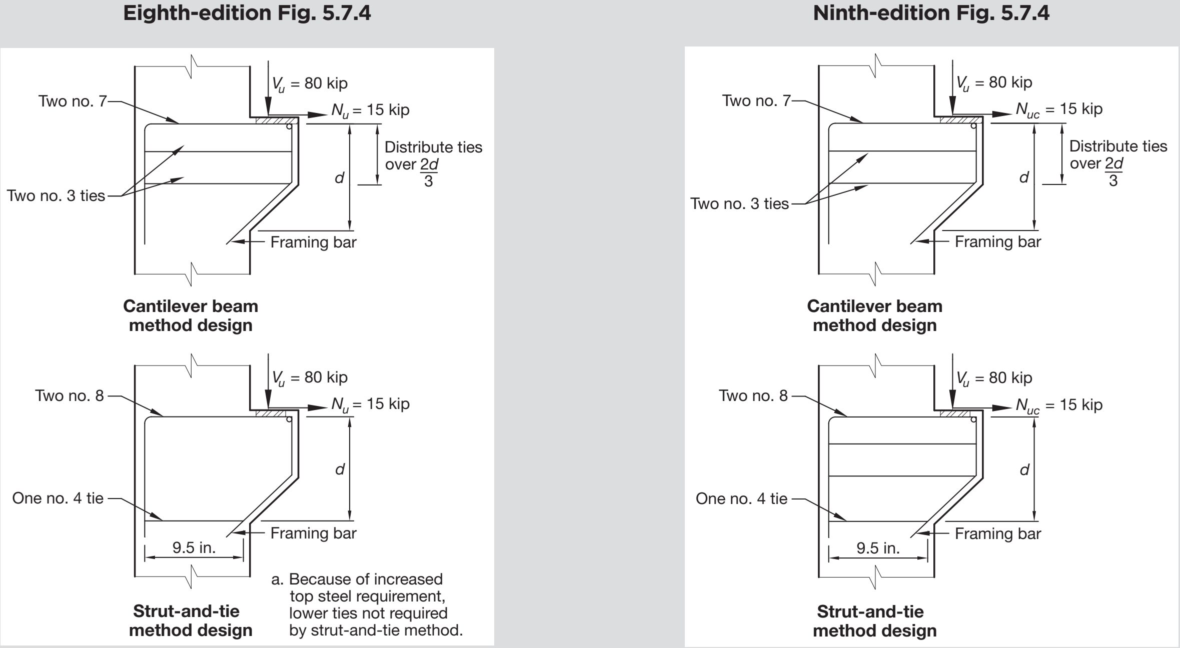


Figure 8. Comparison of corbel design methods. Source: Reproduced from *PCI Design Handbook: Precast and Prestressed Concrete*, eighth edition, and *PCI Design Handbook: Precast and Prestressed Concrete*, ninth edition.

Table 4. Weight of stair components including treads

Stair thickness, in.	Weight of sloped section per foot of width, kip/ft	Added dead load on horizontal projection per foot of width, kip/ft
6	0.137	0.062
8	0.166	0.066
10	0.196	0.071
12	0.225	0.075
14	0.255	0.080
16	0.283	0.083

Source: Data from *PCI Design Handbook: Precast and Prestressed Concrete*, ninth edition (Table 5.13.1).

Changes for consistency with ACI CODE-318-19[20] chapter 17 resulted in the removal of the terms "Condition A" and "Condition B," replacing them with "Supplementary reinforcement present" or "Supplementary reinforcement not present," respectively. This change in terminology should not have any effect on the strength reduction factors used in calculations. Further, the eighth edition notes ACI 318-14 chapter 17 did not address concrete screw anchors; however, the ninth edition notes their inclusion in ACI CODE-318-19,[20] section 17.1.2. Ninth-edition chapter 6 also revises the discussion regarding concrete breakout strength when using reinforcing bars as anchor reinforcement.

For connections made with reinforcing bars in conduits, the guidelines have been revised significantly to increase clarity and update the embedment length data. **Table 5** compares the bar embedment lengths included in the eighth and ninth editions; however, **Figure 9** shows the more significant changes regarding minimum edge distances and conduit confinement.

The dimensions of standard headed studs provided in Table 6.5.2 are updated to be in accordance with stud manufacturer recommendations. The eighth edition assumed the burnoff was a uniform ⅛ in. for all stud diameters. The ninth edition, as provided in a table note, is based on a burnoff of ⅛ in. for ¼ to ½ in. diameter studs and a burnoff of 3⁄16 in. for ⅝ to ⅞ in. diameter studs. Slight revisions were also made to some head thickness values.

Figure 6.5.2, Design tensile strength of stud groups, Case 5: Free edges on three sides, and Case 6: Free edges on four sides, were revised and expanded for clarity.

The committee revised section 6.8, Structural Steel Corbels, based on further review of the source research published in the *PCI Journal*.[30] **Figure 10** was added to clarify nomenclature for general loading with reinforcing contributions.

Section 6.9.1, Cazaly Hanger, includes a correction to the calculation of the lower dowel area A_{vf}, which is proportioned using effective shear friction from chapter 5. The new equation is based on Eq. 5-35, modified for the reaction at the strap as $1.33V_u$, where V_u is the factored shear force.

For column base connections, the ninth edition removes hooked anchor bolts and instead includes the preferred threaded rod with washer and double nut or headed bolt anchors. A footnote was added to Fig. 6.11.2: "Hooked anchor bolts are not recommended but may be used."

Example 6-24 Part B demonstrates the calculations for a seismic base connection design with a reduced footing thickness, as shown in **Fig. 11**. The reduced thickness dictates the use of headed stud anchors for the foundation embedment. The structure is in Seismic Design Category C and is an intermediate

Table 5. Comparison of bar embedment lengths

Bar size, no.	Eighth-edition Table 6.4.1, in.	Ninth-edition Table 6.4.1, in.
3	12	12
4	12	12
5	12	13
6	15	15
7	21	22
8	27	25

Source: Data from *PCI Design Handbook: Precast and Prestressed Concrete*, Eighth Edition, and *PCI Design Handbook: Precast and Prestressed Concrete*, Ninth Edition.

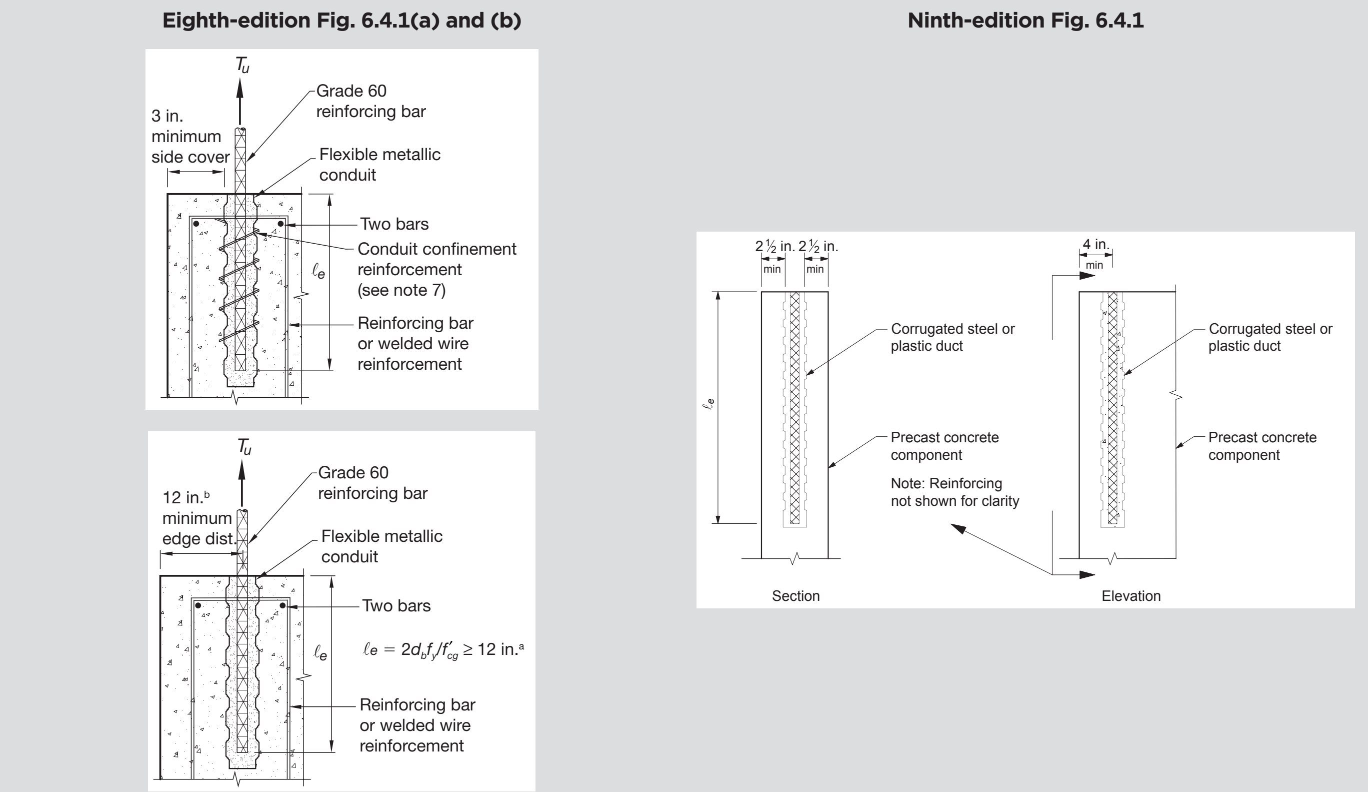


Figure 9. Comparison of minimum edge distances and conduit confinement. Source: Reproduced from *PCI Design Handbook: Precast and Prestressed Concrete*, eighth edition, and *PCI Design Handbook: Precast and Prestressed Concrete*, ninth edition.

shear wall connection. The example includes anchor design and stud group concrete breakout in a higher seismic design category in accordance with ACI CODE-318-19,[20] section 17.10.

Many corrections and clarifications are made to the examples.

Chapter 7—Structural Considerations for Architectural Precast Concrete

Chapter 7 discusses architectural cladding elements, including spandrels and wall panels, and the structural design considerations and responsibilities for design of their connections to the supporting structural system.

The architectural panel design example, which evaluates the controlling wind or seismic demands for the panel and its connections, was also revised.

The design aid on architectural component seismic design parameters (which was revised in ASCE 7-16 to include overstrength factors) was moved from its chapter 4 location in the eighth edition to this chapter, where it is now identified as design aid 7-1; an excerpt of this design aid for the typical precast cladding elements is shown in **Table 6**.

Figure 12 (ninth-edition Fig. 7.5.1) is also new. This figure shows how the component amplification factor a_p and response modification factor R_p affects the cladding factor over the height of the structure. This cladding factor is multiplied by the component weight to get the seismic design force.

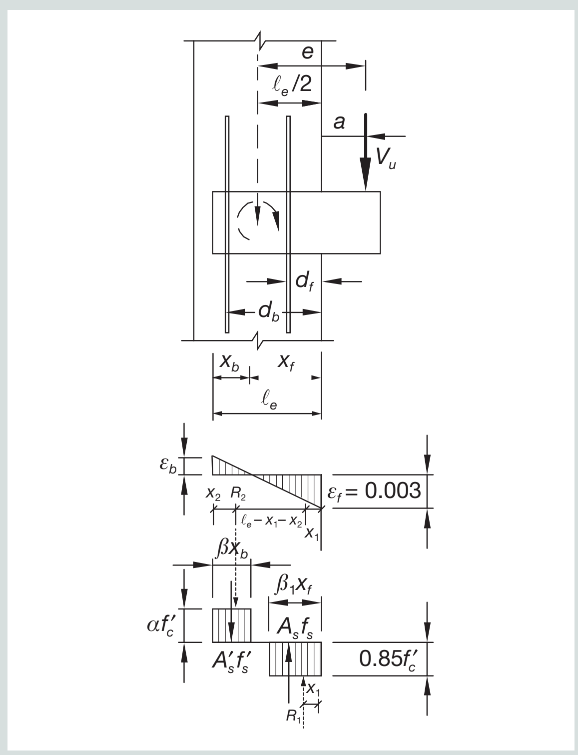


Figure 10. Structural steel corbel general loading with reinforcing configuration. Source: Reproduced from *PCI Design Handbook: Precast and Prestressed Concrete*, ninth edition (Fig. 6.8.4).

Chapter 8—Component Handling and Erection Bracing

Chapter 8 addresses the temporary conditions of stripping, handling, transportation, and erection specific for precast concrete components and structures.

The update provides additional guidance on the use of temporary steel or concrete strongbacks for openings in panels, along with two new design examples for steel strongbacks. **Figure 13** shows a steel strongback used in example 8-1, which uses the single-angle design provisions of the American Institute of Steel Construction's (AISC's) *Specification for Structural Steel Buildings,* ANSI/AISC 360-16.[31] **Figure 14** shows a steel strongback used in example 8-2, which uses composite steel and concrete analysis.

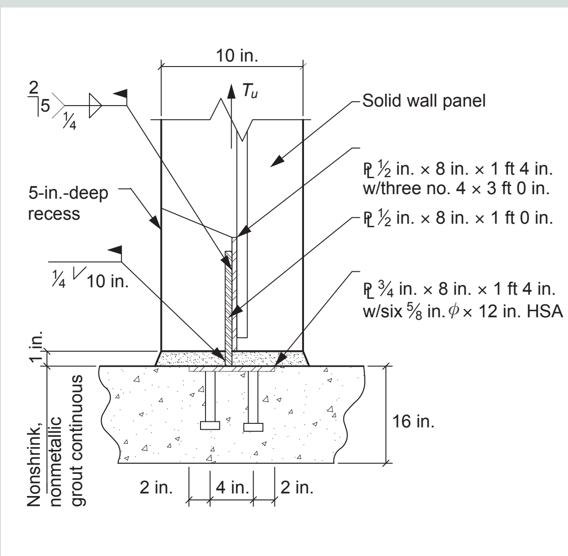


Figure 11. Seismic base connection with headed stud anchors in Seismic Design Category C. Source: Reproduced from *PCI Design Handbook: Precast and Prestressed Concrete*, ninth edition.

A new design example for a spreader beam, based on the American Society of Mechanical Engineers' (ASME's) *Design of Below-the-Hook Lifting Devices* standard (ASME BTH-1[32]), is provided. As the chapter explains, the spreader beam design in ASME BTH-1 addresses the fact that a typical spreader beam is not restrained against rotation about its longitudinal axis at points of support; this differs from steel beam design according to AISC requirements. ASME BTH-1[32] addresses this condition by using a lateral torsional buckling strength coefficient.

The ninth edition clarifies and expands the discussion of erection handling and stability and various related design team responsibilities. The committee also reviewed and updated the discussion and figures for wall panel rotation (tripping) operations. **Figure 15** shows the changes to the sequencing of this operation for an example of handling configuration.

A new section is added regarding the erection plan for precast concrete structures. This section discusses the purpose and need for a project-specific erection plan, which includes both erection sequencing and a stability plan that addresses both global structure stability and local component stability, with additional reference to PCI MNL-127-99, *Erectors' Manual—Standards and Guideline for the Erection of Precast Concrete Products*.[33]

Chapter 9—Materials and Production

Chapter 9 reviews the major materials used in precast and prestressed concrete, fresh and hardened concrete properties, the durability of concrete, corrosion protection of steel reinforcement and connections, and waterproofing issues.

The committee reorganized this chapter and included a new section on production of precast concrete. This section combines a previous discussion on finishes with other new material from PCI's Quality Control Training Programs. The ninth edition includes a new discussion of ultra-high-performance concrete (UHPC) related to its use in precast concrete

Table 6. Architectural component coefficients (excerpt from design aid 7-1)

Architectural component or element	Component amplification factor, a_p[a]	Component response modification factor, R_p	Component overstrength factor, Ω_o[b]
4. Exterior nonstructural wall elements and connections[b]			
a. Wall element	1.0	2.5	n/a
b. Body of wall-panel connections	1.0	2.5	n/a
a. Fasteners of the connection system	1.25	1.0	1.0

Source: Data from *PCI Design Handbook: Precast and Prestressed Concrete*, ninth edition.

Note: n/a = not applicable.

[a]A lower value for a_p shall not be used unless justified by detailed dynamic analysis. The value for a_p shall not be less than 1.00. The value of a_p = 1 is for rigid components and rigidly attached components. The value of a_p = 2.5 is for flexible components and flexibly attached components.

[b]Overstrength where required for nonductile anchorage to concrete and masonry. See ASCE 7-16 section 12.4.3 for seismic load effects including overstrength.

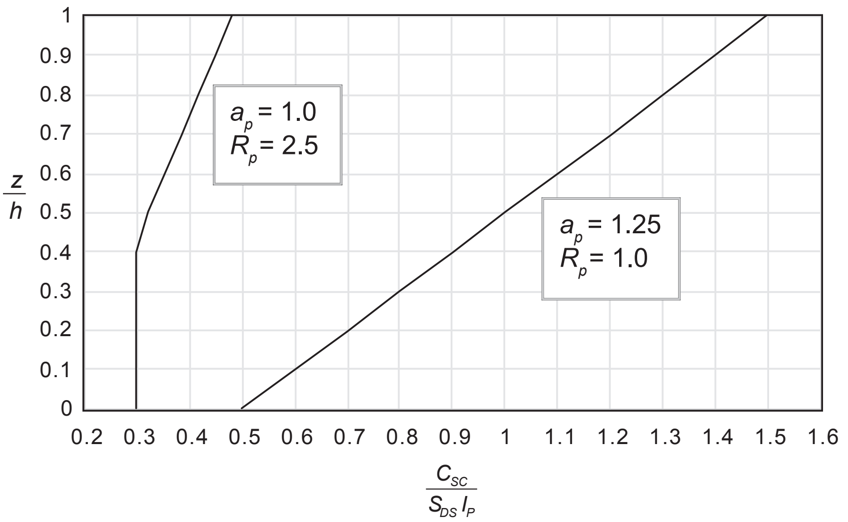


Figure 12. Cladding factor from ninth-edition Fig. 7.5.1. Source: Reproduced from *PCI Design Handbook: Precast and Prestressed Concrete*, ninth edition.

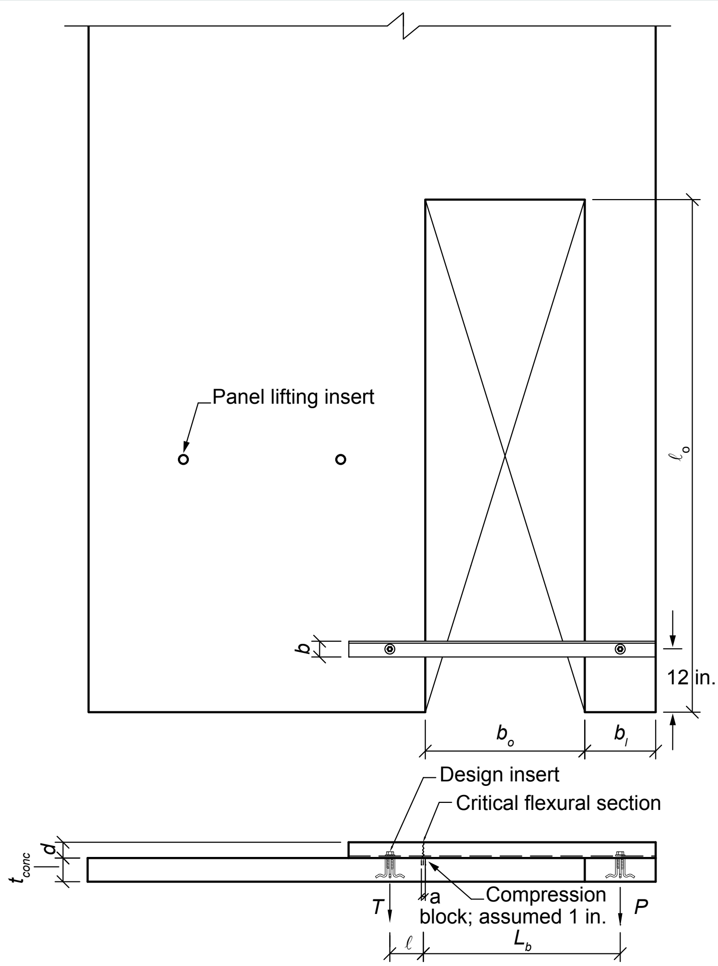


Figure 13. Steel strongback example. Source: Reproduced from *PCI Design Handbook: Precast and Prestressed Concrete*, ninth edition (example 8-1).

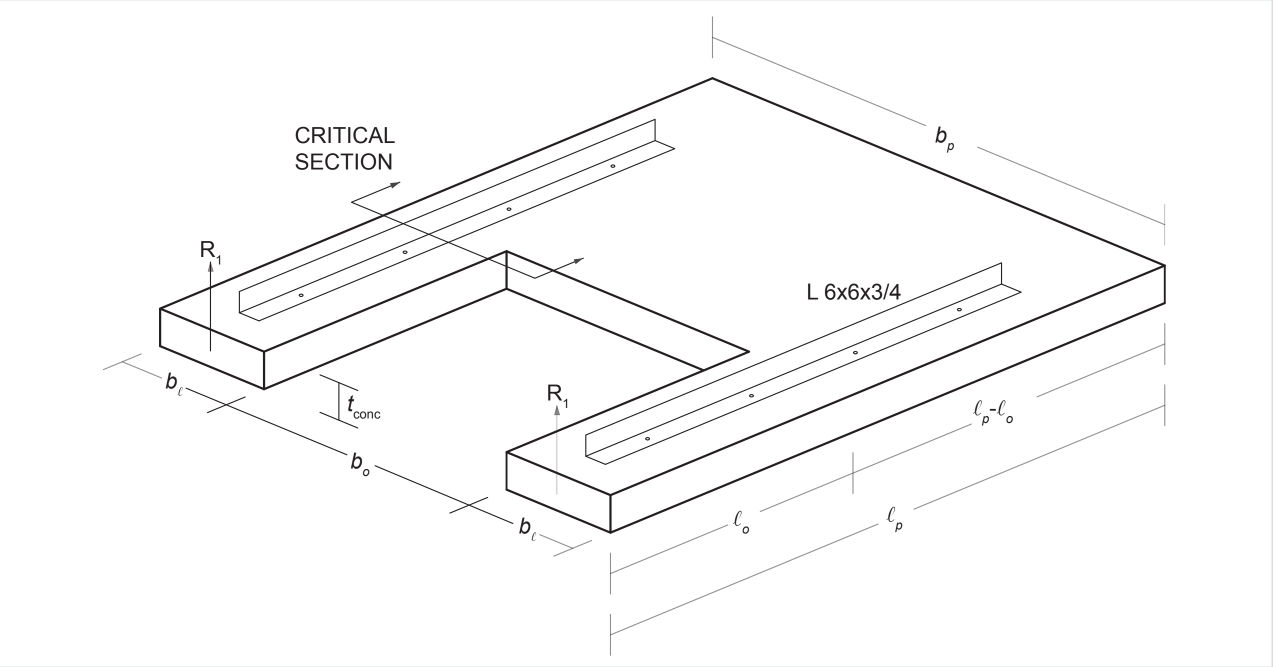


Figure 14. Composite steel strongback example. Source: Reproduced from *PCI Design Handbook: Precast and Prestressed Concrete*, ninth edition (example 8-2).

production, following completion of a major research project on UHPC sponsored by PCI.

Chapter 10—Design for Fire Resistance of Precast and Prestressed Concrete

Chapter 10 provides a concise summary of fire resistance design.

The ninth edition adds a reference to PCI 124-18, *Specification for Fire Resistance of Precast/Prestressed Concrete*,[34] which is referenced in 2021 IBC section 722 for the calculation of fire resistance. It also adds guidance on the classification of restrained and unrestrained conditions, including the use of pour strips to achieve end restraint. The new edition also expanded and illustrated the determination of concrete cover for prescriptive design, as shown in **Fig. 16**, to align with the requirements in PCI 124-18.[34] The chapter provides examples using the rational design method from PCI 124-18, along with a brief explanation of the method's underlying principles.

Chapter 11—Thermal and Acoustical Properties of Precast Concrete

Chapter 11 addresses both thermal properties of precast concrete components and related materials and acoustical properties of precast concrete assemblies.

The committee updated the section on thermal properties to include new sections on heat conduction through the building envelope, steady-state conduction, and the use of building information modeling to simulate thermal performance. It reviewed and updated the thermal properties provided in tables to match the current American Society of Heating, Refrigerating and Air-Conditioning Engineers' *ASHRAE Handbook—Fundamentals*.[35] An example of these updates is shown in **Table 7**.

The ninth edition updates the section on acoustical properties with an expanded discussion of sound absorption, as well as a new section on acceptable noise criteria (NC) and room criteria (RC), both adapted from the Acoustical Society of America's *Criteria for Evaluating Room Noise* ANSI/ASA S12.2-2019[36] for various applications and building spaces.

Chapter 12—Vibration Design of Precast Concrete Floor Systems

This chapter provides guidance for vibration design. Most of this chapter is carried over from the eighth edition with updates based on reference standards. The committee updated the analyzed sections to be consistent with the typical sections included in chapter 3, including updates to Fig. 12.4.1.

The ninth edition expands the guidance regarding the effective weight of the structure for vibration analysis. It states, "The effective weight W_f is normally taken as the unfactored unit dead load (per square foot) of the floor units plus some portion of the design live load, as shown in Table 12.6.2 or at the engineer's judgment, multiplied by the span ℓ and by a width B." Table 12.6.2, shown here as **Table 8**, is based on AISC *Design Guide 11: Vibrations of Steel-Framed Structural Systems Due to Human Activity*,[37] Table 3-1.

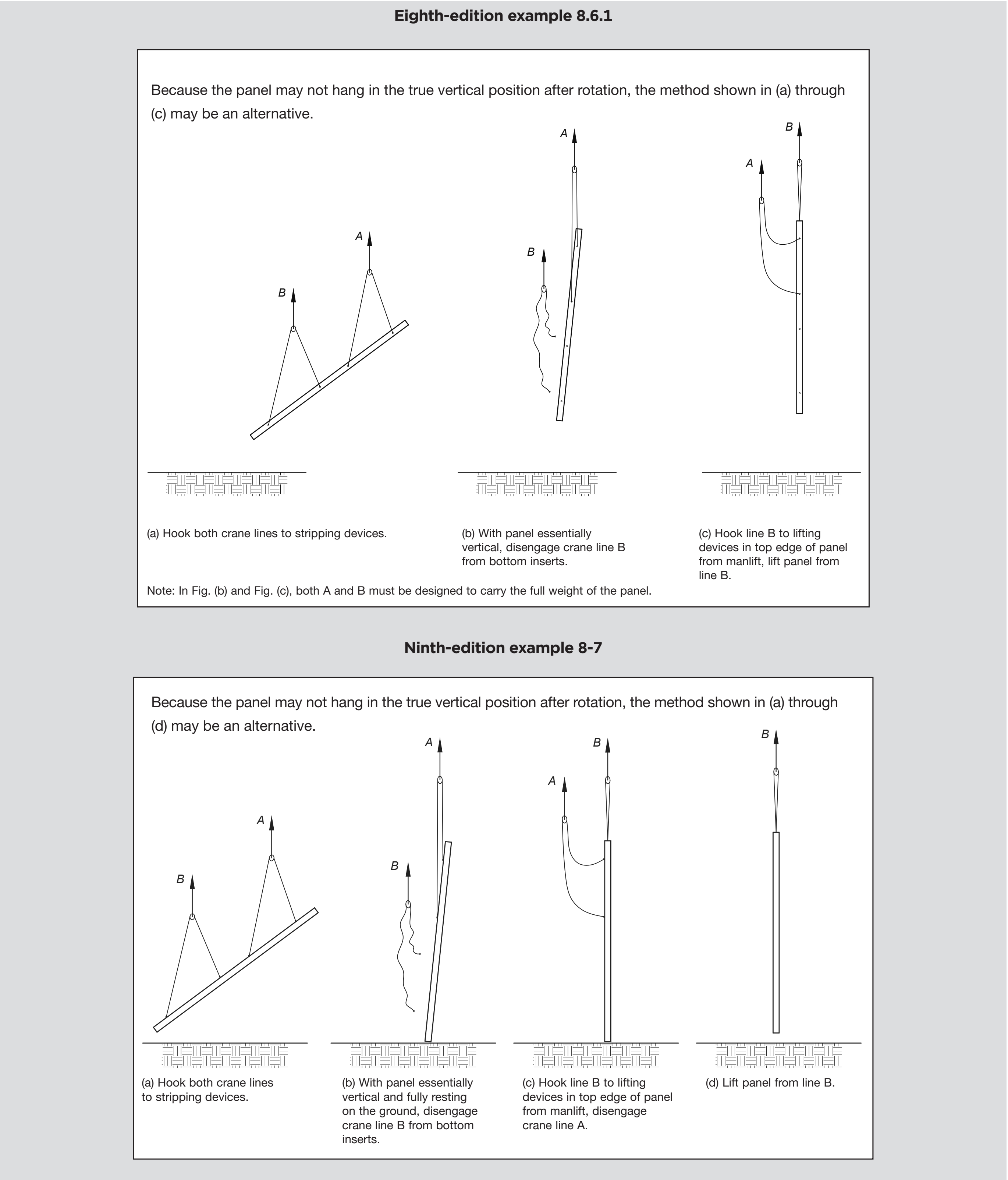


Figure 15. Panel tripping procedure comparison. Source: Reproduced from *PCI Design Handbook: Precast and Prestressed Concrete*, eighth edition, and *PCI Design Handbook: Precast and Prestressed Concrete*, ninth edition.

Chapter 13—Design for Extreme Events

As previously noted, chapter 13 in the eighth edition addressed "Tolerances for Precast and Prestressed Concrete." The committee determined that this content was redundant with both ACI ITG-7-09, *Specification for Tolerances for Precast Concrete*,[38] which is referenced in section 1901.7.2 of the 2021 IBC, and a new PCI standard on tolerances, *Specification for Tolerances of Precast Concrete*, published in 2025 as PCI 135-25.[39] Accordingly, the chapter on tolerances was deleted.

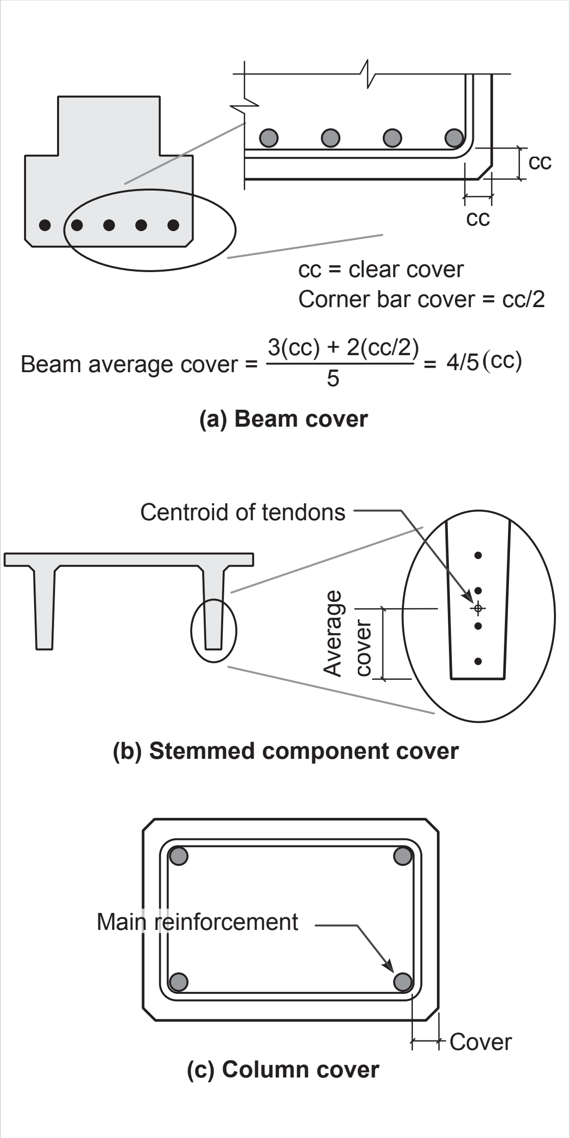


Figure 16. Cover determination for prescriptive design. Source: Reproduced from *PCI Design Handbook: Precast and Prestressed Concrete*, ninth edition (Fig. 10.8.1).

The eighth-edition handbook also included "Appendix A: Blast-Resistant Design of Precast, Prestressed Concrete Components" and "Appendix B: Design for Structural Integrity and Disproportionate Collapse." The ninth edition simplifies and combines these two appendices into a new chapter titled "Design for Extreme Events." In addition, the chapter includes "Tsunami Loads and Effects," "Flood Design," "Impact Loads," and "Tornadoes and Hurricanes."

"Tsunami Loads and Effects" is based on ASCE 7-16,[22] chapter 6; it is, by nature, a design consideration for coastal regions and is defined as a series of waves typically resulting from earthquake-induced uplift of subsidence of the seafloor.

Storm protection structures, such as safe rooms and storm shelters, have become required for more structures and communities and ASCE 7 continues to expand design requirements to resist tornadoes and hurricanes. The information provided in this section is primarily based on ICC 500,[40] *Standard for the Design and Construction of Storm Shelters*, and FEMA P-361,[41] *Safe Rooms for Tornadoes and Hurricanes: Guidance for Community and Residential Safe Rooms*. The section also notes that ASCE 7-22[26] has a new tornado provision for risk categories III and IV, which has been adopted in IBC 2024.[42]

Table 8. Recommended superimposed live loads for walking vibration analysis

Occupancy	Live load, lb/ft²
Paper office	11
Electronic office	6 to 8
Residence	6
Assembly area	0
Shopping mall	0

Source: Data from *PCI Design Handbook: Precast and Prestressed Concrete*, ninth edition (Table 12.6.2).

Table 7. Comparison of conductivity values

	Eighth edition		Ninth edition
Rigid insulation material	Thermal resistance *R* per inch of thickness, 1/*k*	Effective conductivity, *k*	Conductivity *k*
Extruded polystyrene	5.00	0.20	0.18 to 0.20
Expanded polystyrene	3.1 to 4.2	0.24 to 0.32	0.24 to 0.26
Polyisocyanurate	5.5 to 6.3	0.16 to 0.18	
Polyisocyanurate unfaced			0.16 to 0.17
Polyisocyanurate with foil facers			0.15 to 0.16

Source: Data from *PCI Design Handbook: Precast and Prestressed Concrete*, eighth edition, and *PCI Design Handbook: Precast and Prestressed Concrete*, ninth edition.

Chapter 14—Standard Practices

Chapter 14 provides standard practices within the precast industry. The names of its two main sections have been updated:

- In the eighth edition, section 14.1 was "Standard Operations Practice Recommendations for Precast Concrete." In the ninth edition, this section is now "Recommended Practice on Precast Concrete Operations."
- In the eighth edition, section 14.2 was "Recommendations on Responsibility for Design and Construction of Precast Concrete Structures." In the ninth edition, this section is now "Recommended Practice on Responsibility for Precast Concrete Construction."

The main content and organization of each section remain similar to the prior edition; however, as PCI has become an ANSI-approved standards-writing organization, the committee identified a need to update these names to properly convey that these sections are PCI recommendations for a quality project rather than a standard or code requirements.

The committee also added to this chapter terminology for team members from the 2021 IBC and additional clarifications and recommendations from "Recommendations on Responsibility for Design and Construction of Precast Concrete Structures."[43] It updated the PCI Plant Certification categories to include the expanded architectural categories AA, AB, AC, AD, and AT.

The *PCI Standard Design Practice Ref ACI 318-19,*[44] which is developed by the PCI Building Code Committee, is also included.

Chapter 15—Reference Information

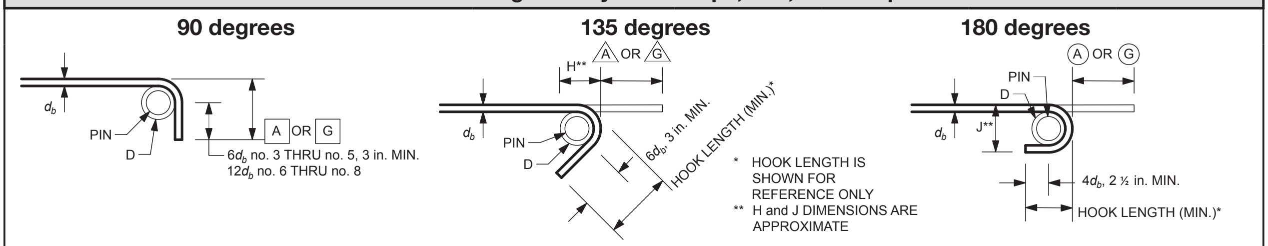
Chapter 15 collects information to serve as a resource, quick reference, or repository to aid in the design of precast concrete components and structures. The chapter has been continually maintained and updated after its original inclusion as Part 11 in the first-edition *PCI Design Handbook*.

The table of minimum uniformly distributed and concentrated live loads was updated to align with the 2021 IBC and rearranged to improve clarity. Notably, the 2015 IBC live load table included footnotes a through m for various specific design requirements; the 2021 IBC has placed these requirements in separate subsections of 2021 IBC section 1607. Thus, the table includes a column to "Also see 2021 IBC Section."

The committee reviewed and revised extensively the beam design equations and diagrams, including camber and rotation coefficients and torsion diagrams; it added clarifications and graphic corrections and improved organization.

Based on changes in the Concrete Reinforcing Steel Institute's (CRSI's) *Manual of Standard Practice*,[45] tables and guidance for hook dimensions were modified. **Figure 17**, excerpted from design aid 15-17, shows the CRSI standard hook geometry for

Standard hook geometry for stirrups, ties, and hoops[a]



Bar size, no.	*D*, in.	90 degrees	135 degrees		180 degrees	
		A or *G*, in.	*A* or *G*, in.	*H*, in.	*A* or *G*, in.	*J*, in.
3	2	4½	4½	2¾	5	2¾
4	2½	4¾	5	3	5½	3½
5	3¼	6	6	3¾	6½	4½

Special bending hook geometry for stirrups, ties, and hoops[a]

Bar size, no.	*D*, in.	90 degrees	135 degrees		180 degrees	
		A or *G*, in.	*A* or *G*, in.	*H*, in.	*A* or *G*, in.	*J*, in.
3	1½	4	4¼	2½	5	2¾
4	2	4½	4½	3	5½	3½
5	2½	6	5½	3¾	6½	4½

Figure 17. Standard hook geometry compared with special bending hook geometry. Source: Reproduced from *PCI Design Handbook: Precast and Prestressed Concrete*, ninth edition (design aid 15-17).

Table 9. Development length of standard hooks for Grade 60 reinforcement in 6000 psi concrete

Bar size, no.	Eighth edition (based on ACI 318-14)	Ninth edition (based on ACI CODE-318-19)
3	3.3*	3.2*
4	4.3*	5.0*
5	5.4*	7.0
6	6.5	9.1
7	7.6	11.5
8	8.7	14.1
9	9.8	16.8
10	11.0	20.2
11	12.2	23.6

* Below the minimum value of $8d_b$ or 6 in., shown only for illustration.

Note: d_b = reinforcing bar diameter.

stirrups, ties, and hoops along with geometry classified as "special bending." The need to specify "special bending" may apply to precast concrete producers that subcontract bar bending rather than bending in house. For additional information, see Brown.[46] The typical hook dimension tables have also separated the hook geometry, specifically the finished bend diameter *D*, for bars bent prior to hot-dip galvanizing based on ASTM A767,[47] Table 2.

A significant update was required for the development length tables to be in accordance with significant changes in ACI CODE-318-19,[20] in particular an increase in the development length for standard hooks. **Table 9** provides an example comparison between the required hook development lengths from the eighth edition (based on ACI 318-14[19]) and the ninth edition (based on ACI CODE-318-19[20]). See "The Most Notable Changes from ACI 318-14 to ACI 318-19 for Precast Concrete"[28] for additional information.

In addition to Grade 60 reinforcement, the ninth edition provides new tables and design aids for the use of Grade 80 reinforcement introduced in ACI CODE-318-19;[20] however, Grade 100 was not included in this edition. For straight bar development, a reinforcement grade modification factor is required along with the higher yield strength used in the calculation of development length; for hook bar development, only the higher yield strength applies.

The chapter updates design aids for standard bolts, nuts, and washers and includes a new table for high-strength bolts, as those used in structural joints for structural steel. Dimensions for nominal bolts diameters larger than 1½ in. were deleted because of limited use in the industry. Design aid 15-30, regarding the recommended nuts and washers for bolts and threaded rods, was updated, as shown in **Fig. 18**.

The section on metric conversions from the eighth edition was removed.

Conclusion

As stated in the handbook's foreword, the *PCI Design Handbook* is a living document. Comments related to any aspect of the handbook are encouraged and much appreciated. This handbook has had a very intensive review at several levels. It must be understood, however, that all errors may not have been observed and corrected during these reviews. PCI therefore collects and publishes errata based on input of users of the handbook. The errata will also be posted on the PCI website under "Publication Errata" in the "Design Resources" section. Address all comments via email to ihberrata@pci.org.

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Eighth-edition design aid 15.5.3

Design aid 15.5.3. Recommended Nuts and Washers for Bolts and Threaded Rods

Diameter, in.	ASTM A36 Threaded Rod[b]	ASTM A307 Bolts and Threaded Rod[b]	ASTM A325 Bolts	ASTM F1554 Threaded Rod[a]			ASTM A193 Threaded Rod
		Grade A[c] and Grade C[d]	Type 1	Grade 36	Grade 55	Grade 105	Grade B7
1/4 to 1 1/2	Grade A hex	Grade A hex	Grade C heavy hex[e,f]	Grade A hex	Grade A hex[g]	Grade D hex[h]	Grade 2H heavy hex
More than 1 1/2 to 4	Grade A heavy hex	Grade A heavy hex	n/a	Grade A heavy hex	Grade A heavy hex	Grade DH heavy hex	Grade 2H heavy hex
Bolt/rod specification	ASTM A563	ASTM A563	ASTM A563	ASTM A563	ASTM A563	ASTM A563	ASTM A194
Washer specification	ASTM F844	ASTM F844	ASTM F436	ASTM F436	ASTM F436	ASTM F436	ASTM F436

[a] Nuts of other grades and styles of ASTM A563 (see ASTM A563 Table 3) or ASTM A194 (see ASTM A194 Table 3) having a proof load stress equal to or greater than the minimum tensile strength specified for the rod are also suitable.
[b] Nuts of other grades and styles of ASTM A563 (see Table 3 of ASTM A563) having greater specified proof load stresses are also suitable.
[c] Bolts with minimum tensile strength of 60 ksi.
[d] Straight or bent anchor bolts conforming to ASTM A36.
[e] Nuts conforming to ASTM A194 Grade 2H are considered a suitable substitute.
[f] For galvanized nuts, use Grade DH heavy hex nut.
[g] For galvanized nuts, use Grade A heavy hex nut.
[h] For galvanized nuts, use Grade DH heavy hex nut.

Ninth-edition design aid 15-30

DESIGN AID 15–30

Recommended Nuts and Washers for Bolts and Threaded Rods[a]

	ASTM A307[b]		ASTM F3125	ASTM F1554			ASTM A193
	Grade A	Grade B[c]	Grade A325 Type 1	Grade 36[d]	Grade 55	Grade 105	Grade B7
Size range, in.	1/4 – 1 1/2	1/4 – 1 1/2	1/2 – 1 1/2	1/2 – 1 1/2	1/2 – 1 1/2	1/2 – 1 1/2	≤ 2 1/2
Min. tensile strength f_u, ksi	60	60-100	120	58	75	125	125
Min. yield strength f_y, ksi	n/a	n/a	92	36	55	105	105
Nut	ASTM A563 Gr. A, hex	ASTM A563 Gr. A, heavy hex	ASTM A563 Gr. DH, heavy hex	ASTM A563 Gr. A, hex	ASTM A563 Gr. A, hex	ASTM A563 Gr. DH, heavy hex	ASTM A194 Gr. 2H, heavy hex
Washer	ASTM F844	ASTM F844	ASTM F436 Type 1	ASTM F436	ASTM F436	ASTM F436	ASTM F606

[a] For galvanized fasteners, nuts, and washers, see ASTM F2329.
[b] ASTM A307 Grade C has been replaced by ASTM F1554 Grade 36.
[c] ASTM A307 threaded rod is not usually produced to Grade B, but it can be when specified by the purchaser.
[d] ASTM A36 is a steel grade, not a fastener specification. Technically, all thread rod made from A36 steel should be ordered to a fastener specification such as A307 Grade A, A307 Grade B, F1554 Grade 36, or SAE J429 Grade 2. The appropriate fastener specification will depend on the application. However, some companies stock all thread rod manufactured from A36 steel and can certify it as such upon request.

Figure 18. Comparison of eighth-edition design aid 15.5.3 and ninth-edition design aid 15-30. Source: Reproduced from *PCI Design Handbook: Precast and Prestressed Concrete*, eighth edition, and *PCI Design Handbook: Precast and Prestressed Concrete*, ninth edition.

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