Background and discussion of the *PCI Design Handbook: Precast and Prestressed Concrete*, 8th Edition

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Foreword

PCI updates and publishes the *PCI Design Handbook: Precast and Prestressed Concrete*[1] in cycles coincident with publication of the American Concrete Institute's (ACI's) *Building Code Requirements for Structural Concrete (ACI 318-14) and Commentary (ACI 318R-14)*.[2] The eighth edition of the *PCI Design Handbook*, published in 2017, continues that tradition. Each update of the *PCI Design Handbook* reflects the modifications adopted by ACI 318 and other relevant codes and standards, the most recent research completed on precast and prestressed concrete, current industry practice, and the experience of designers regularly engaged in the design of precast and prestressed concrete structures.

Introduction

The publication of the eighth edition of the *PCI Design Handbook* continues to meet the goals set forth by the Precast/Prestressed Concrete Institute, which was established in 1954 as the Prestressed Concrete Institute. The current name was adopted in 1989 to better reflect the interests of both prestressed concrete producers and those that manufacture nonprestressed precast concrete components. The goal is to advance the design, manufacture, and use of precast and prestressed concrete.

The eighth-edition *PCI Design Handbook*'s primary objective remains the same as that of the first edition,[3] published in 1971; that 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."

This background and discussion paper is the seventh document of its type. The first was published for the second edition of the *PCI Design Handbook*[4] and was titled "Background and Discussion on PCI Design Handbook Second Edition."[5] It was published in the January–February 1980 issue of *PCI Journal*. Subsequent papers with the same intent and similar titles were published in the following issues of *PCI Journal*:

- For the third-edition *PCI Design Handbook*:[6] May–June 1988 issue[7]
- For the fourth-edition *PCI Design Handbook*:[8] Novem-

ber–December 1996 issue[9]

- For the fifth-edition *PCI Design Handbook*:[10] July–August 1998 issue[11]
- For the sixth-edition *PCI Design Handbook*:[12] March–April 2006 issue[13]
- For the seventh-edition *PCI Design Handbook*:[14] Fall 2010 issue[15]

These papers are available on the PCI website at https://www.pci.org/PCI/Publications/PCI_Journal/PCI_Journal.aspx.

Purpose

The main purpose of the background and discussion of the eighth edition of the *PCI Design Handbook* is to identify significant changes from the seventh edition on a chapter-by-chapter basis and explain the rationales for these changes.

Synopsis of changes from the seventh-edition *PCI Design Handbook*

The eighth edition of the *PCI Design Handbook*, while similar to the seventh edition in many ways, incorporates modifications that generally fall into one of the following categories:

- It includes updated information reflecting changes from ACI 318-05[16] to ACI 318-14,[2] the American Society of Civil Engineers' ASCE 7-05[17] to ASCE 7-10,[18] and *International Building Code 2006* (IBC 2006)[19] to IBC 2015.[20]
- It incorporates the seventh-edition errata[21] that was published as a supplement to the *PCI Journal* Fall 2012 issue. This can be found on the PCI website, PCI.org, under "Publication Errata" in the "Design Resources" section.
- It incorporates some recommendations by the seventh-edition *PCI Design Handbook* Blue Ribbon Review Committee that could not be included in the seventh edition.
- It includes updated information based on current standard practices of the industry.
- It includes updated information based on results of recent research in the industry.
- It expands the text of selected topics to provide a more comprehensive discussion.
- Selected text, figures, tables, design aids, and examples have been rewritten, modified, and edited for improved clarity.

Some things in the eighth-edition *PCI Design Handbook* remain unchanged from the seventh edition. The number of chapters has remained at 15, and their titles are unchanged. The seventh-edition appendix, "Impact of ACI 318-08 on this Handbook," has been removed for obvious reasons. Three appendices have been added as a result of the PCI Industry Handbook Committee's desire to provide more emphasis on the topics of blast design, structural integrity and disproportionate collapse, and seismic design of diaphragms. **Table 1** outlines the differences from the seventh edition to the eighth edition of the *PCI Design Handbook*.

Users of the *PCI Design Handbook* will observe that certain industry standard style items, such as the use of feet and inch marks in drawings and details and the use of the number symbol (#) to designate reinforcing bar sizes, were changed to the current PCI publication style for the benefit of our international readers. For example, 10'-6" is now written 10 ft 6 in., and #6 is now written no. 6, except at the beginning of a sentence, where it is No. 6.

Users may also observe that the seventh-edition list of examples and design aids immediately following the overall table of contents has been deleted because it was considered of limited usefulness.

The committee process

It is of interest to review the process by which the eighth edition of the *PCI Design Handbook* was created. As soon as the seventh edition was published in 2010, PCI established a new Industry Handbook Committee. It consisted of 24 voting members and 8 consulting members. Thirteen of these people served on the seventh-edition committee. They represent various interests within the industry and include 19 specialty engineers, 7 plant engineers, 3 engineers-of-record, 1 trade-association engineer, and 2 academics.

The process used was as follows:

1. The seventh edition was used as the baseline, with the understanding that IBC 2015 would be the model code basis for the eighth edition, along with standards ASCE 7-10 and ACI 318-11.[22] In late 2013, the committee received a directive from the PCI Technical Activities Council (TAC) that, as a result of changes to IBC 2015, the handbook was now to be based on ASCE 7-10, including Supplement No. 1, and ACI 318-14. An appropriate time extension accompanied the directive. At this point, many chapters had progressed through many of the following steps, but they all came back to a modified step 3 to bring them into conformance with the new standards, after which the previously completed following steps were repeated.

2. The committee reviewed the overall structure and agreed to keep the same 15-chapter format but to provide 3 appendices to cover some topics for which considerable new information was available: blast design, disproportionate collapse, and diaphragm seismic design methodology (DSDM).

3. For each chapter, a subgroup was established with 1 to 10 members, including a chairperson. The subgroup conducted a detailed review of the existing chapter and an exhaustive review of research and publications relevant to the subject material within that chapter. After analysis and discussion regarding improved or updated content,

Table 1. Comparison of contents of seventh and eighth editions of the *PCI Design Handbook*

Chapter	Comments	Seventh edition					Eighth edition				
		Pages	Figures	Tables	Design examples	Design aids	Pages	Figures	Tables	Design examples	Design aids
1		28	63	0	0	0	28	71	0	0	0
2		18	0	0	0	0	30	0	0	0	0
3		64	7	34*†	0	11	58	7	31*†	0	10‡
4	New appendixes A and B replace parts of chapter 4	98	34	4	13	26	100	25	2	12	32§
5		152	38	8	48	15	162	45	8	47	5
6		116	37	11	26	14	122	40	7	27	11
7		36	18	4	3	0	28	14	3	2	0
8		28	27	4	4	0	34	27	4	5	0
9		42	22	10	0	0	48	23	9	n/a	0
10		26	17	13	4	0	26	9	8	4	13
11		26	4	15	4	0	28	4	14	4	0
12		10	2	3	3	0	12	2	3	3	0
13		34	14	3	2	0	36	13	3	2	0
14		36	0	0	0	0	18	0	0	0	0
15		62	0	0	0	36	58	0	0	0	31
Appendix	Deleted from eighth edition	22	6	9	0	0	n/a	n/a	n/a	n/a	n/a
Appendix A	New, replaces section 4.9	n/a	n/a	n/a	n/a	n/a	28	17	2	3	0
Appendix B	New, largely replaces section 4.3	n/a	n/a	n/a	n/a	n/a	18	7	1	1	0
Appendix C	New	n/a	n/a	n/a	n/a	n/a	16	5	4	0	0
Index		10	0	0	0	0	29	0	0	0	0
Totals		808	289	118	107	102	879	309	99	110	102

Note: n/a = not applicable.

* Considers each component load table as a separate table.

† Does not consider normalweight and lightweight load tables for the same component as separate tables.

‡ Considers column design aids separately.

§ Considers wind maps separately for different risk categories in chapter 4.

each subgroup developed a draft of their respective chapters.

4. Each chapter was then edited by the technical editor, and a committee ballot version was created.

5. Each chapter was balloted by the committee, with resolution of all comments during meetings of the full committee. This process included 18 face-to-face meetings and 31 web-based teleconferences during the seven years of development. There were 90 official committee ballots.

6. A committee-approved version was created and sent to TAC for balloting and approval.

7. Each chapter was balloted by TAC, with resolution of all comments by both TAC and the Industry Handbook Committee.

Original bridge

New bridge

Figure 1. Walnut Lane Memorial Bridge.

8. Based on these approved versions, a blue-ribbon-review version was created. This final review was done by a Blue Ribbon Review Committee made up of plant engineers, specialty engineers, consulting engineers, academicians, and associate members, whose names are listed in the foreword to the handbook. Each member of this committee is a recognized leader in the analysis and design of precast/prestressed concrete products or an expert in a closely related field. After a review period of more than eight weeks, the group met for two days with the Industry Handbook Committee and offered valuable comments. Many of their comments were accepted as improving the publication, and others are being carried forward for ninth-edition consideration.

9. A final version of each chapter was then created and thoroughly reviewed by the original chapter subgroup. This process resulted in further corrections and improvements.

10. At this point in the process, PCI staff brought the material into conformance with its current style guide and prepared print-ready layouts of each chapter, which were reviewed by the technical editor and the entire Industry Handbook Committee.

It is commendable that the eighth edition of the *PCI Design Handbook* was created primarily through the volunteer efforts of the committee members and many others. Thousands of hours were devoted to its development. The following presents a chapter-by-chapter review of the significant changes from the seventh edition, as well as the rationales behind these changes.

Chapter 1—Precast and Prestressed Concrete: Applications

This chapter is intended to provide users of the handbook with a general understanding of the many applications of precast and prestressed concrete used in buildings and other structures. For bridges, a separate publication by PCI, the *Precast Prestressed Concrete Bridge Design Manual*,[23] is available.

As is typical with each new edition of the *PCI Design Handbook*, many of the photographs, as well as their captions and related text, have been updated to illustrate the current state of the art. Although the handbook is not intended for bridges, a photograph of the Walnut Lane Memorial Bridge (**Fig. 1**) has been retained to remind users of the beginning of the prestressed concrete industry in the United States. The original bridge, shown on the left in Fig. 1, served well for 40 years and was replaced with a pretensioned superstructure in 1990, shown on the right in Fig. 1. For additional information related to the history of the industry, refer to *Reflections on the Beginnings of Prestressed Concrete in America*,[24] published in 1981, and *PCI 50 Years: Visions Taking Shape*,[25] published in 2004. These documents commemorate the 25th and 50th anniversaries of PCI, respectively. The former is available on the PCI website under “History” in the “About” section.

In addition, there are significant updates to section 1.1.3, “Sustainability and High-Performance Building Code Considerations,” including a new section 1.1.3.1, “Precast Concrete Industry and Sustainability,” which expands the material on this important topic. Section 1.2.1.8, “Storm Shelters,” is new and reflects interest in this market (**Fig. 2**).

Chapter 2—Notations

This chapter includes the notations for the entire handbook and, as was the case in the seventh edition, is organized by chapters of the handbook. Content has been updated for eighth-edition usage. Notations identical to those used in ACI 318-14 are identified with “(ACI)”. It is important to note that due to the breadth of topics covered in the handbook, there are some cases where the same variable name is used for different variables.

This discrepancy typically exists only among chapters and not within them.

Definitions are not included because the committee considered it more user-friendly to include definitions either at the beginning of each chapter or in the text where a term is used.

Chapter 3—Preliminary Design of Precast/Prestressed Concrete Components

Several figures depicting framing systems in section 3.2, “Preliminary Analysis,” have been updated to better reflect their intent.

Load tables for double tees with cast-in-place topping have been changed to use a topping thickness of 3 in. (rather than 2 in.) because 3 in. thickness is more commonly used in current construction. Topping strength, where applicable, is now specified as 3000 psi (the value previously used but not specified), and lightweight concrete, where applicable, is now specified as 115 lb/ft^3 (also the value previously used but not specified).

Load tables for 8DT24, 8DT32, and 15DT26 were deleted because they are not common in current construction. It is interesting to observe the evolution of double tees and single tees through the years as evidenced by the load tables in the previous editions of the handbook (**Table 2**).

Design Aid 3.12.3 “Design Strength Interaction Curves for Precast, Prestressed Double-Tee Wall Panels” was removed because of the reduced use of double-tee walls.

Chapter 4—Analysis and Design of Precast/Prestressed Concrete Structures

The chapter on the analysis and design of precast and prestressed concrete structural systems has been updated to reflect the requirements of ACI 318-14,[2] ASCE 7-10,[18] and IBC 2015.[20]

Figure 2. Storm shelter/gymnasium exterior and interior.

Table 2. History of double-tee and single-tee load tables in the *PCI Design Handbook*

Edition		1st	2nd	3rd	4th	5th	6th	7th	8th
Year published		1971	1978	1985	1992	1999	2004	2010	2017
Topping		2 in.	2 in.	2 in.	2 in.	2 in.	2 in.	2 in.	3 in.
Untopped and topped double tees	4DT14	X							
	5DT18	X							
	6DT12, 6DT16, 6DT20	X							
	8DT12	X	X	X	X	X			
	8DT14, 8DT16, 8DT18, 8DT20	X	X	X	X				
	8DT24	X	X	X	X	X	X	X	
	8DT32		X	X	X	X	X	X	
	10DT24			X	X	X	X	X	X
	10DT32	X	X	X	X	X	X	X	X
	12DT28, 12DT32					X	X	X	X
Untopped and topped single tees	8ST24, 8ST28, 8ST32	X							
	8ST36	X	X	X					
	10ST24, 10ST28, 10ST32	X							
	10ST36	X		X					
	10ST40, 10ST44	X							
	10ST48	X	X	X					
Pretopped double tees	10DT26, 10DT34				X	X	X	X	X
	12DT30, 12DT34					X	X	X	X
	15DT26						X	X	
	15DT30, 15DT34						X	X	X

Note: 1 in. = 25.4 mm.

Organizational changes include moving most of the structural integrity information to appendix B, "Design for Structural Integrity and Disproportionate Collapse," and eliminating blast material in favor of including a formatted reprint of a published PCI Blast Resistance and Structural Integrity Committee report[26] as the new appendix A, "Blast-Resistant Design of Precast, Prestressed Concrete Components." Also, seventh-edition section 4.2.6.1, "Load Factors for Diaphragms," was deleted because it was not code based, and seventh-edition section 4.8.3.3, "Performance-Based Design," was deleted because appendix C, "Precast Concrete Diaphragm Design in Accordance with Alternative Provisions of ASCE 7-16," now covers those concepts. Seventh-edition section 4.8.3.4, "Wind and Low Seismic Hazard," was expanded and moved to section 4.8.4.2.

Wind design information has been updated to reflect the ASCE 7-10 change to the use of design wind speeds that incorporate building risk category. This includes wind-speed maps and load combinations with wind. Wind-related design aids have been expanded with additional information taken from ASCE 7-10.

Numerous seismic design updates have been made. Material on intermediate precast concrete shear walls was expanded and now includes special requirements for connections and wall piers. Intermediate precast concrete shear walls may even be advantageous where ordinary shear walls are allowed (SDC A or B) because the larger *R*-values (4 for a bearing wall system and 5 for a frame system) may allow a lower design lateral load. Discussion regarding options for connecting intermediate shear walls at vertical edges was greatly expanded (**Fig. 3–5**).

The new section 4.6.1, "Column Base Connections," was added to discuss several alternatives for moment-resisting column bases.

New Example 4.5.3.1, "Calculation of Required Length of Yielding Element," shows how the yielding element of an intermediate precast concrete shear wall base connection may be designed to meet the ductility requirement of IBC 2015 section 1905.1.3, requiring it to have 80% of its design strength at design displacement.

Example 4.5.12.1 has been changed from a three-level, three-bay parking structure to a five-level, two-bay parking structure to illustrate the benefits of using high-flexibility shear walls and to permit complete hand calculations in lieu of providing computer-generated results. **Figure 6** shows the structure plan and elevation. Seismic design includes calculations for the approximate period, the alternate approximate period, and the Rayleigh's period, as well as stability and P-delta checks. Wind loads are also calculated and compared with the seismic results. The diaphragm analysis was moved out and expanded to create a new Example 4.8.3.1. Here, chord and collector forces are determined, as well as diaphragm–to–shear wall load transfer requirements. **Figure 7** shows an excerpt from this example.

Chapter 5—Design of Precast and Prestressed Concrete Components

Updating the component design chapter to the applicable current codes was challenging due to the major reorganization that occurred in ACI 318-14. Identifying the new section numbers and equation numbers took considerable effort, but fortunately there were no substantive technical changes necessitated by code changes. The major changes in chapter 5 came as a result of new research.

The changes fall into four categories:

- organization
- updates
- revisions
- new research

The organization of the chapter remained unchanged except for two minor exceptions. Concrete corbel design was moved from being a subsection of compression members (seventh-edition section 5.9.4) to standing on its own as section 5.7, "Concrete Corbels." Section 5.14, "Design Procedure Following ACI 318-14," was added to assist users in transitioning to the reorganized ACI 318-14.

Other than code updates, several seldom-used tables and design aids were removed and related text and examples were revised or deleted accordingly. Also, several design examples have been updated to reflect current practices, such as wider

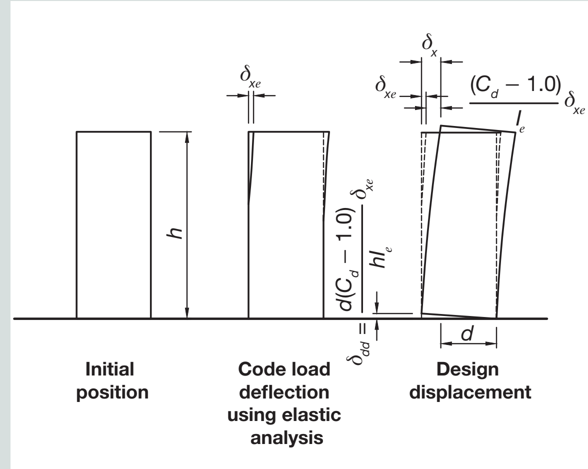


Figure 3. Single panel displacement of intermediate precast concrete shear wall.

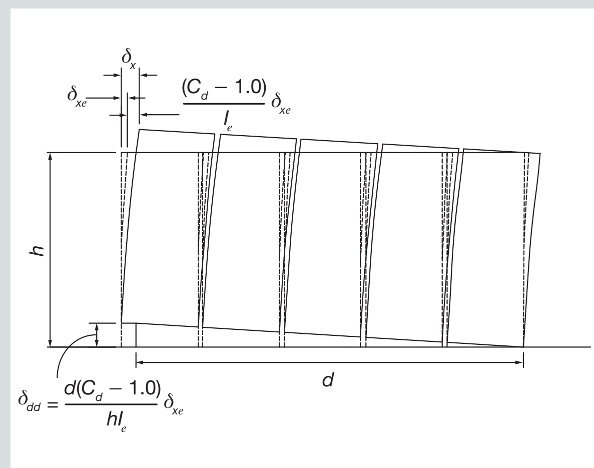


Figure 4. Rigidly connected series of intermediate precast concrete shear walls.

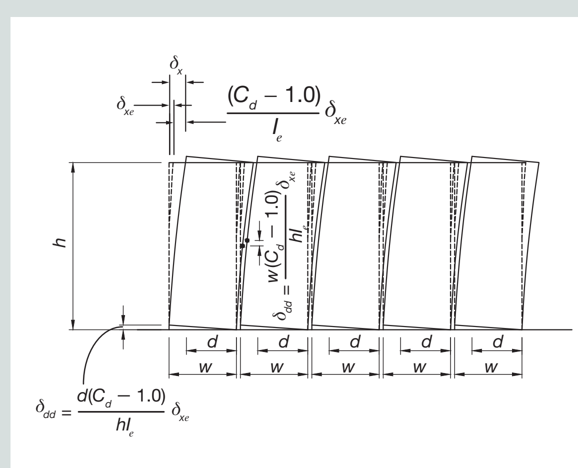


Figure 5. Ductilely connected series of intermediate precast concrete shear walls.

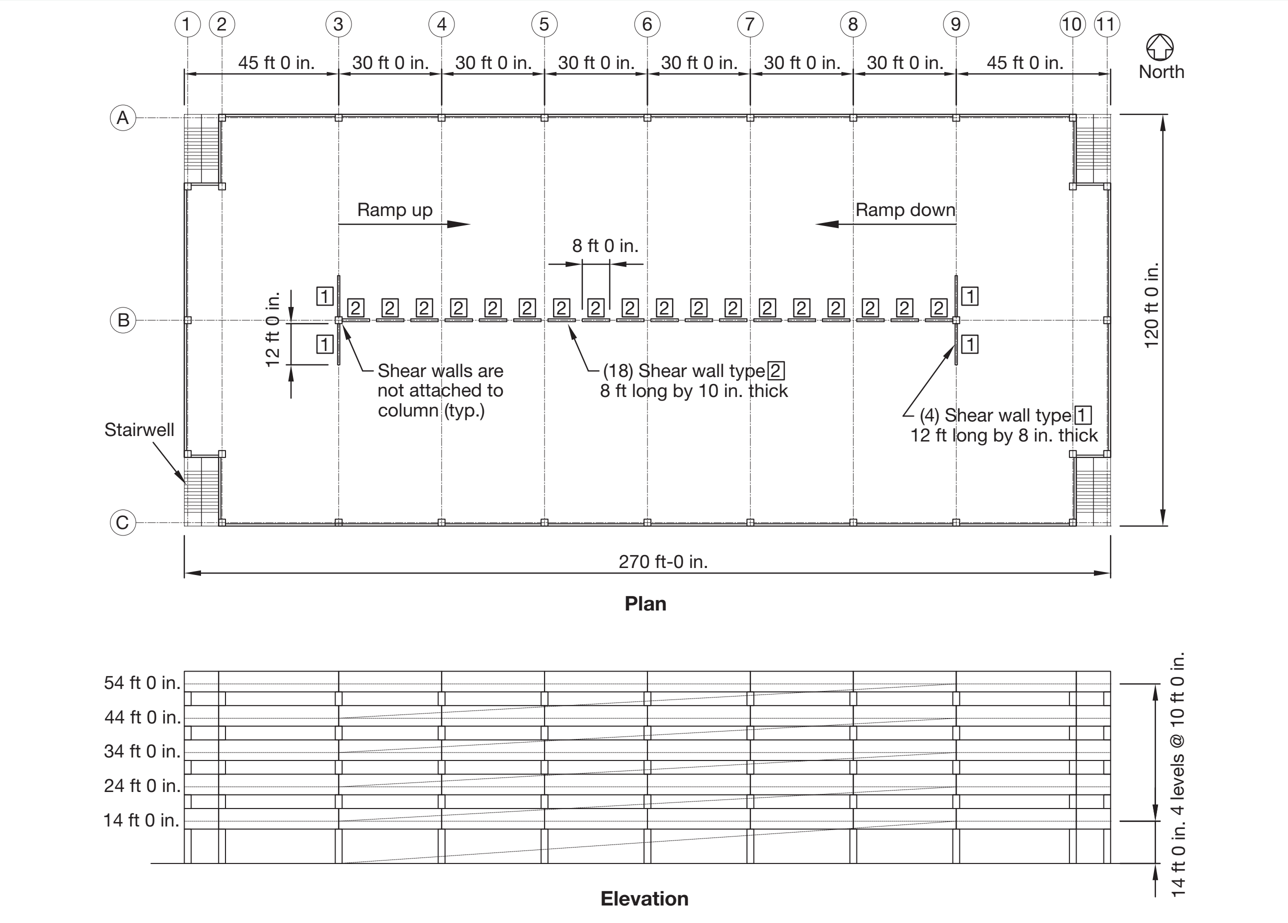


Figure 6. Parking structure from Example 4.5.12.1.

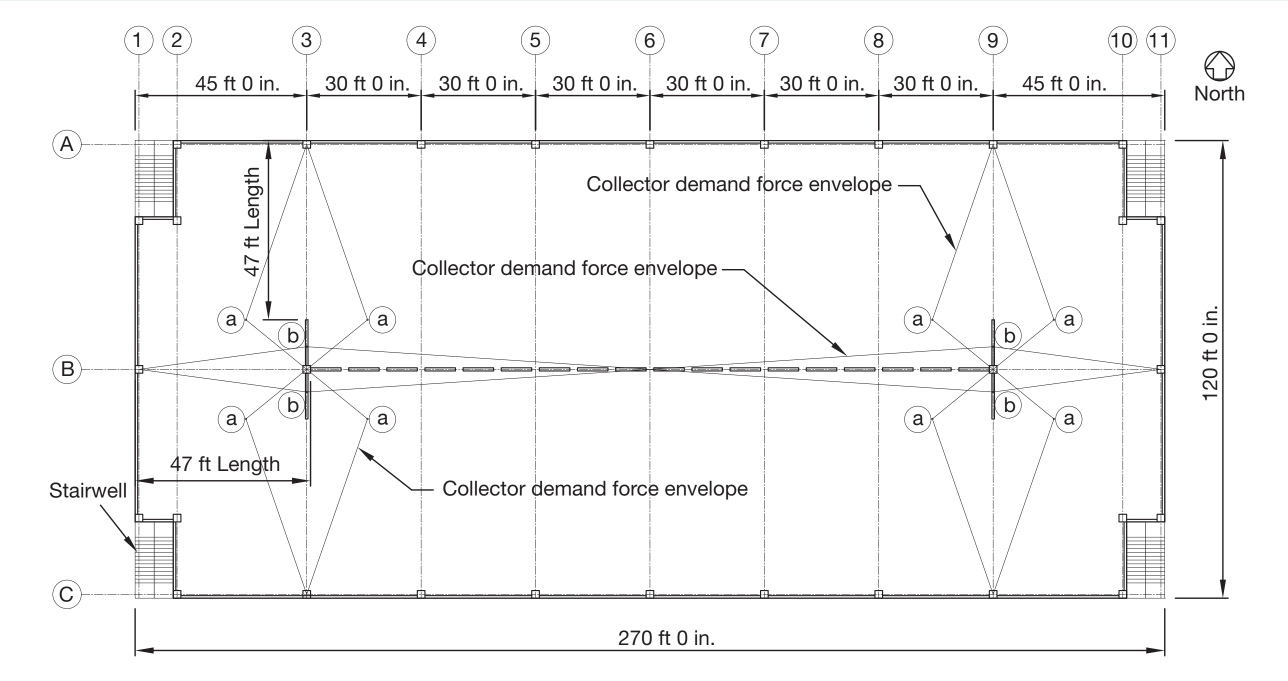


Figure 7. Collector demand envelopes from Example 4.8.3.1.

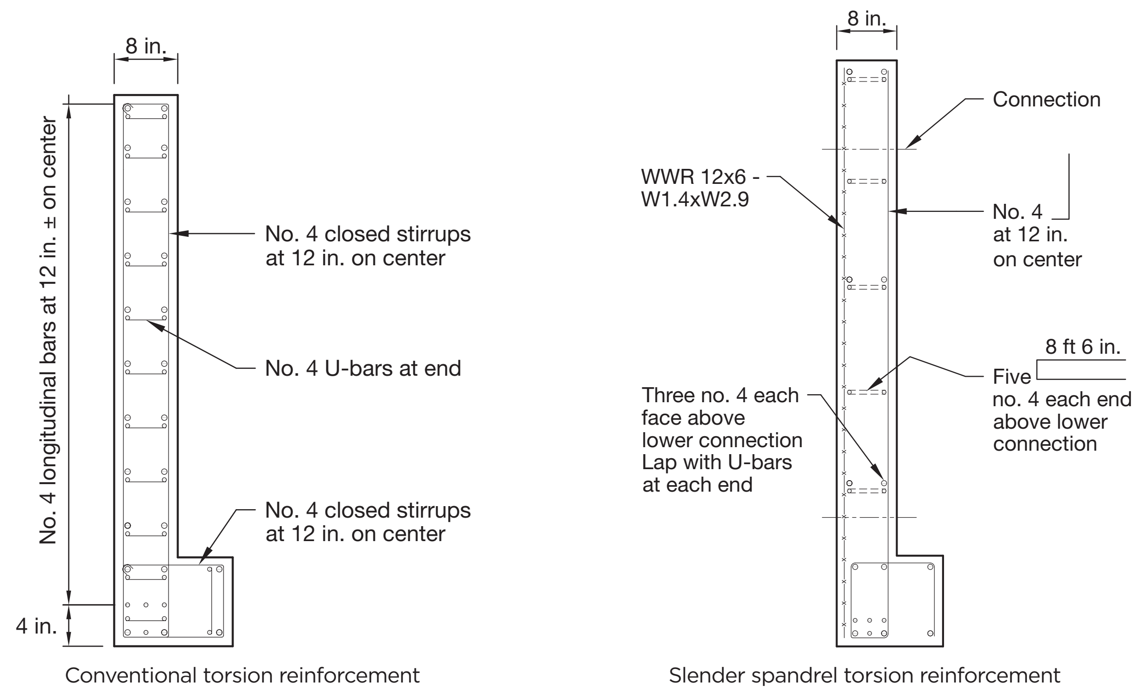


Figure 8. Spandrel reinforcement comparison.

double tees and thicker (3 in. rather than 2 in.) topping on topped double tees.

Numerous revisions were made, but the vast majority were minor in nature or simply clarifications. One somewhat significant revision was the correction of the decompression stress calculation for determining the moment of inertia of a cracked prestressed section. This occurs in section 5.2.2.2, "Prestressed Component Design," cracked section analysis step 2. It now correctly reflects the underlying source.[27] This revision required follow-through in Examples 5.2.2.5 and 5.2.2.6. Another revision fixed the *m*-factor term used for calculating the hanger steel in inverted tee beams with unequally loaded ledges. See section 5.6.4, "Attachment of Ledge to Web," Eq. 5-85.

Three research projects resulted in significant changes to some design procedures. The first resulted in a new section 5.4.2, "Slender Spandrel Method." This design method is based on the two-part research report, "Development of a Rational Design Methodology for Precast Concrete Slender Spandrel Beams."[28,29] The results of that research allow simplification of the spandrel transverse reinforcement by recognizing that slender beams resist eccentric loading primarily by plate bending rather than by torsion, and thus closed ties are not required. **Figure 8** shows torsion reinforcement summaries from comparable examples that illustrate the differences between the conventional and the new methods. In order for a spandrel to be designed by this new method, it must be simply supported, have evenly spaced loads applied along the bottom edge, be laterally restrained at two points at each end, and have an aspect ratio (height divided by web thickness) of not less than 4.5.

The second research project involved the design of dapped thin-stemmed members and resulted in substantial changes to section 5.5.3, "Dapped-End Bearing." The research report is titled *Development of Rational Design Methodologies for Dapped Ends of Prestressed Concrete Thin-Stemmed Members*,[30] and the design requirements apply to all dapped components meeting these criteria: stem width is 8 in. or less, hanger reinforcement is vertical or inclined no less than 50 degrees from horizontal, and dap height is no greater than one-half of the overall component height. The study included full-scale tests of several reinforcement configurations (**Fig. 9**) as well as analytical models. New requirements for thin-stemmed components include additional shear checks for the extended nib, new shear checks for the full-depth region just beyond the dap, and new cover and bend requirements for the hanger (diagonal tension) reinforcement.

The third research project involved the design of beam ledges and resulted in substantial changes to section 5.6.1, "Shear Strength of Ledge." The research report is titled *Behavior and Design of Directly-Loaded L-Shaped Beam Ledges*[31] and applies to the punching shear checks for ledges of prestressed and nonprestressed beams. Although no reports of failures in practice have been reported, the research found that the previous equations for punching shear could be unconservative. The revised Eq. 5-76 through 5-79 (**Fig. 10**) consider a somewhat

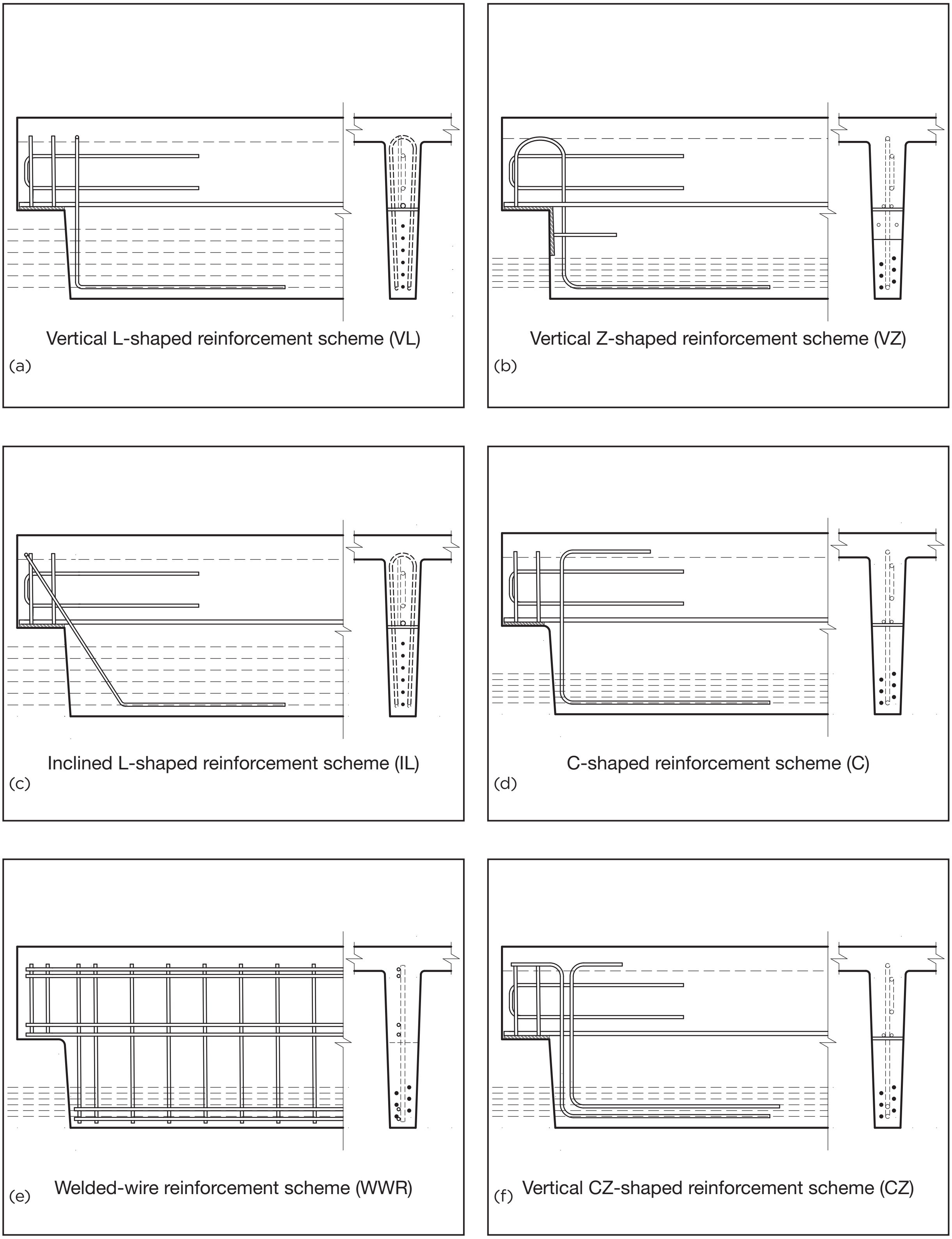


Figure 9. Configurations of dap reinforcement for thin-stemmed components that were studied in *Development of Rational Design Methodologies for Dapped Ends of Prestressed Concrete Thin-Stemmed Members*. Source: Wiss, Janney, Elstner Associates. 2015. Development of Rational Design Methodologies for Dapped Ends of Prestressed Concrete Thin-Stemmed Members. Northbrook, IL: Wiss, Janney, Elstner Associates.

For concentrated loads, not near the ends, where $d_e \geq 0.5b_t + h_\ell + l_p$ a symmetric failure controls the design punching shear strength of the ledge ϕV_n, which is determined as the lesser of Eq. 5-76 and 5-77.

$$\phi V_n = \phi\lambda\gamma\beta\sqrt{f_c'}h_\ell\left(b_t + 2h_\ell + 2\ell_p\right) \quad \text{(Eq. 5-76)}$$

$$\phi V_n = \phi 0.5\lambda\gamma\beta\sqrt{f_c'}h_\ell\left(b_t + 2h_\ell + s + 2\ell_p\right) \quad \text{(Eq. 5-77)}$$

Conditions where failure planes overlap must also be checked.

For concentrated loads that are near ends, where $d_e < 0.5b_t + h_\ell + l_p$, an asymmetric failure controls the design punching shear strength of the ledge ϕV_n, which is determined as the lesser of Eq. 5-78 and 5-79.

$$\phi V_n = \phi\lambda\gamma\beta\sqrt{f_c'}h_\ell\left(0.5b_t + h_\ell + d_e + \ell_p\right) \quad \text{(Eq. 5-78)}$$

$$\phi V_n = \phi 0.5\lambda\gamma\beta\sqrt{f_c'}h_\ell\left(0.5b_t + h_\ell + d_e + s + \ell_p\right) \quad \text{(Eq. 5-79)}$$

where

h_ℓ = height of beam ledge, in.

ℓ_p = length of beam ledge projection, in.

b_t = bearing width, in.

s = minimum spacing of concentrated loads, in.

d_e = distance from center of load to end of ledge, in.

β = coefficient of shear strength based on R (see Fig. 5.6.2)

$\gamma = \sqrt{1 + 10\dfrac{f_{pc}}{f_c'}}$, a factor for the effect of prestressing

f_{pc} = average prestress force after losses divided by gross concrete area of beam, psi

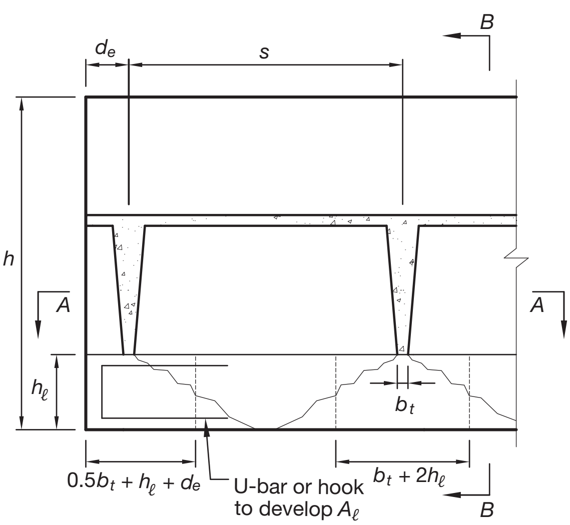


Figure 10. Ledge punching shear equations.

different failure surface and have new factors that account for the level of prestress in the beam as well as the ratio of applied loads to nominal capacities (**Fig. 11**). These new design equations will likely require evaluations at multiple locations.

Another revision based on research was to section 5.13.1, "Transverse Strength of Double-Tee Flanges," which changed the effective width resisting a concentrated load from a 60-degree angle to an influence ratio of 3:1.[32]

Chapter 6—Design of Connections

In addition to numerous code reference updates, clarifications, and minor revisions, the following changes are notable.

Seventh-edition Table 6.2.1, "Diaphragm Overstrength Factors," was deleted because guidelines for precast concrete diaphragm designs have been improved and new alternative provisions are discussed in appendix C, "Precast Concrete Diaphragm Design in Accordance with Alternative Provisions of ASCE 7-16." Also, the remainder of section 6.2.3, including Table 6.2.2, was removed because it was deemed to be an oversimplification of information that should come directly from IBC 2015.

Section 6.4.2, "Deformed Bar Anchors," now includes explicit equations for tension and compression capacities of anchorage assemblies with deformed bar anchors and references the use of shear friction when such anchorages are subjected to

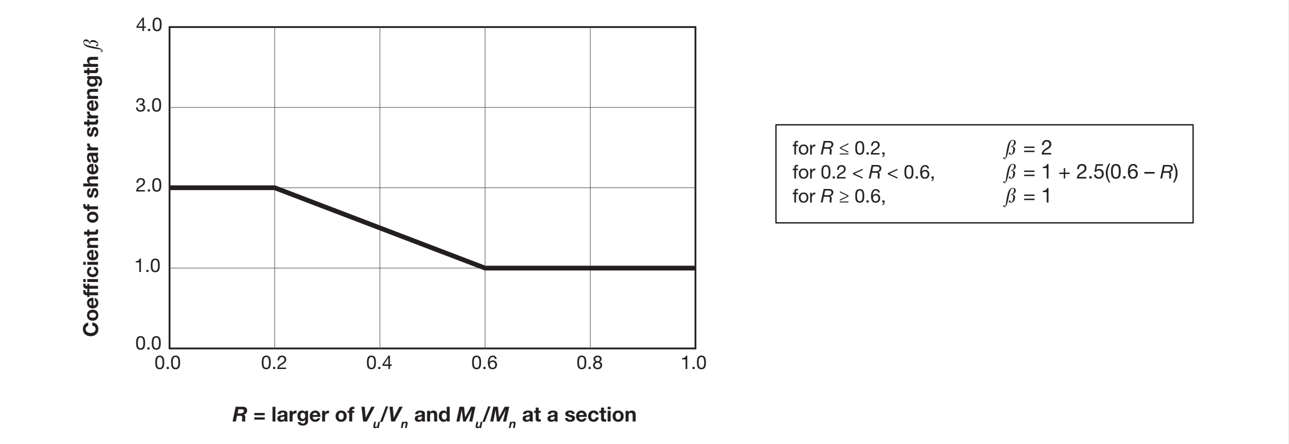


Figure 11. Coefficient of shear strength β.

shear loading. The deformed bar anchor calculations in Example 6.13.5 were updated accordingly.

Section 6.4.4.1, "Reinforcing Bars in Conduit," and Fig. 6.4.1 have been revised to better reflect the original supporting research in regard to cover and confinement, as well as to discuss more recent research.

Section 6.4.9, "Post-Installed Anchors," has expanded information on expansion anchors, adhesive anchors, and grouted anchors, as well as a new section on concrete screw anchors. Example 6.4.9.1, "Post-Installed Expansion Anchors Using ACI 318-14 Chapter 17," and Example 6.4.9.2, "Post-Installed Adhesive Anchors Using ACI 318-14 Chapter 17," are new.

Section 6.5.2, "Headed Stud Anchors—Steel Strength," now includes a discussion on plate fixity/prying action, including new Example 6.5.2.1. **Figure 12** shows components of anchor forces considering plate prying.

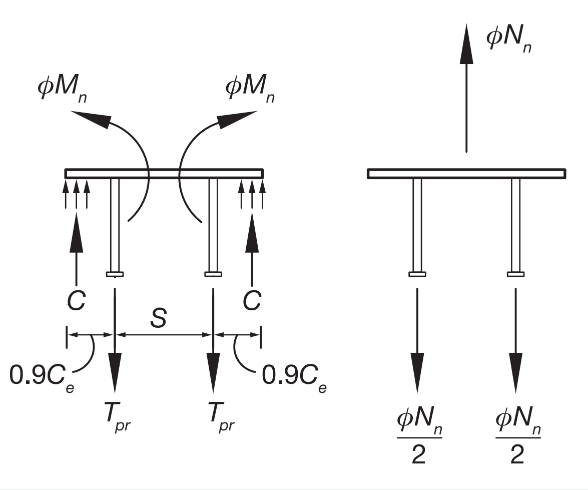


Figure 12. Anchor forces considering plate prying.

Table 6.5.4, "Summary Table of Headed Stud Anchor Group Concrete Shear-Strength Equations," was rearranged for clarity.

Figure 6.5.5, which shows the corner transition to a front-edge breakout, was revised to provide greater clarity.

Section 6.5.9, "Shear at an Angle," was added to address shear loading that is not square to the grid of headed studs. This issue is not addressed in ACI 318-14.

Section 6.6.1.1, "Steel Plates," was added to discuss some connection plate bending considerations.

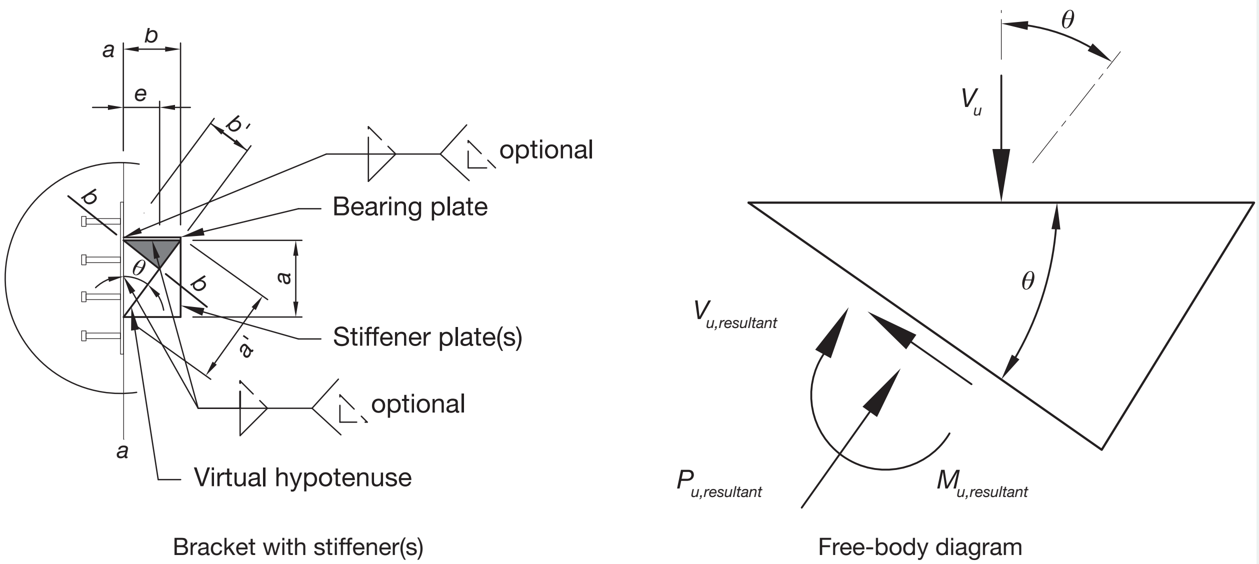
Seventh-edition sections 6.6.6, "Triangular Stiffener Design," and 6.6.7, "Non-triangular Stiffener Design," have been replaced by the completely new eighth-edition section 6.6.6, "Stiffener Design," which is based on the procedure given in the American Institute of Steel Construction *Steel Construction Manual*, 14th edition[33] (**Fig. 13**).

Table 6.7.1, "Stainless Steel Property Ranges," was updated to reflect the wide range of strengths of stainless steel available in the market. Also, the elongation values have been deleted.

Fig. 6.7.3, which shows the elastic vector method–typical geometry, has been revised to clarify the general three-dimensional loading on an element of a weld.

In section 6.9.1, "Cazaly Hanger," a design step has been added that allows the A_v steel to be omitted if necessary for shallow components. The calculations in this step are based on recent research.[34]

Example 6.13.2, "Plate-and-Bar Diaphragm Shear Connection," was revised to resolve the free body diagram imbalance. This typical connection embed has two reinforcing bar anchors flared out, in this case at 45 degrees. In the seventh edition, the design force in the bar in tension was calculated using a ϕ-factor of 0.90 and the bar in compression was



Notes: A horizontal axial force is not shown because it is transferred directly to the embed plate by the weld between the top plate and the embed plate. a–a and b–b are potential failure planes. See Fig. 6.6.6 for free-body diagram of shaded area.

Figure 13. Steel bracket design.

calculated using a ϕ-factor of 0.65. But by this analysis, the components of the bar forces perpendicular to the shear force were not equal and opposite, so the design-strength free body diagram was out of balance. The Industry Handbook Committee decided that the analysis could be considered strut-and-tie modeling, in which case the ϕ-factor for both the tension and compression bars becomes 0.75 and the free body diagram is balanced. The capacity difference is negligible.

Example 6.13.6, “Seismic Base Connection Design,” is new. It shows the design of a base connection for an intermediate precast concrete shear wall. The design complies with ACI 318-14 section 18.5.2, limiting yielding to one steel or reinforcing element and ensuring that all other elements of the connection have a minimum design strength of 1.5 times the yield strength of the yielding element. **Figure 14** shows the setup of the example.

Seventh-edition Examples 6.13.5, “Wall-to-Wall Shear Connection;” 6.13.6, “Wall-to-Wall Shear Connection with Combined Loading;” and 6.13.7, “Ordinary Moment Frame Connection,” have been deleted to make way for new material.

Design Aids 6.15.1 and 6.15.2 (fillet welds) were expanded to include electrodes up to E110.

Seventh-edition Design Aids 6.15.3 through 6.15.5 (reinforcing bar welds) are now 6.15.3 through 6.15.6. The previous Design Aid 6.15.3 was split into 6.15.3 and 6.15.4, with welded splices separated from bars welded to a plate along sides. Values for Grade 40 bars are no longer included in any of these, and Grade 80 bars are considered in all. For all bars welded to a plate, A36 plate is used and only E70 electrodes are shown because the A36 base material controls. For bar splices, values for E100 have been added and values are now given for developing 125% and 150% of bar yield strength rather than 100%.

Design Aid 6.15.7, “LRFD Design Strength ϕR_n and ASD Allowable Strength R_n/Ω of Bolts and Threaded Fasteners,” was reorganized for clarity, and additional types and grades of threaded rods and bolts have been added.

Four seventh-edition design aids were deleted. Design Aid 6.15.7, “High-Strength Coil Bolt and Coil Threaded Rod Selection Chart,” was deleted because there is no ASTM standard for coil-threaded connectors; users should consult the specific manufacturer for design information. The other three, Design Aid 6.15.8, “Strength of Connection Angles. Vertical Load;” Design Aid 6.15.9, “Strength of Connection Angles. Horizontal Load;” and Design Aid 6.15.12, “Column Base-Plate Thickness Requirements,” were deemed unnecessary with the widespread use of computers.

Chapter 7—Structural Considerations for Architectural Precast Concrete

There were few changes to this chapter beyond general updating per code changes and some trimming of less-used information and information found elsewhere in the handbook.

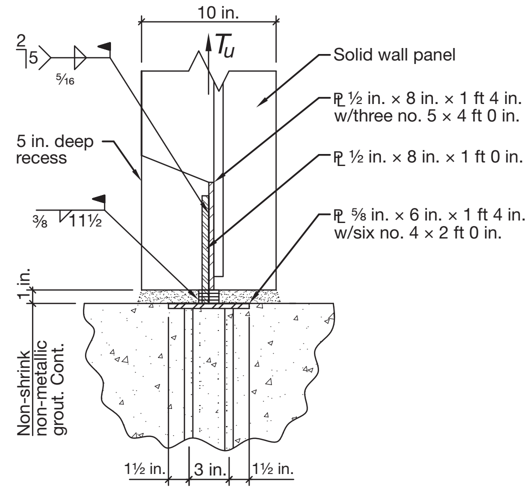
The most notable change is the addition of section 7.3.1, “Structural Engineer of Record [SER],” which points out the design information that the code requires the SER to provide

Example 6.13.6

Seismic Base Connection Design

Problem:

Determine the design tension capacity ϕT_n of the base connection for an intermediate precast concrete shear wall that is part of the seismic-force-resisting system for the applied load T_u shown.



Given:

Concrete foundation:

- Concrete strength f'_c = 4000 psi normalweight
- Foundation thickness = 28 in.

Precast concrete wall panel:

Concrete strength f'_c = 5000 psi normalweight

- Welds: E70xx electrodes

ACI 318-14 Section 18.5.2.1 requires that the above connection yields only at the steel elements or reinforcement.
ACI 318-14 Section 18.5.2.2 requires that any elements not designed to yield must have a design strength equal to 1.5 times the yield strength of the yielding element. IBC 2015 amends ACI 318, requiring the connection to satisfy the deformation demand resulting from the design displacement of the intermediate precast concrete shear wall.

This example assumes that the yielding will occur in the reinforcement of the wall embed plate and illustrates the requirements of ACI 318-14 Sections 18.5.2.1 and 18.5.2.2. Refer to Section 4.5.3.2 for a discussion of IBC 2015 Section 1905.1.3 deformation requirements and Example 4.5.3.1 for a numerical example.

Figure 14. Setup of Example 6.13.6.

to the specialty structural engineer (SSE)—also referred to as the precast engineer—including codes, loads, story drifts, acceptable locations for panel gravity and lateral connections, and any other design criteria.

As a result of ASCE 7-10 using design level wind loads, sections 7.5.1 and 7.5.2 of the seventh edition, which covered ASCE 7-05 methods 1 and 2, have been replaced by section 7.5.1, "Wind Loads: ASCE 7-10, Chapter 30, Part 4," and section 7.5.2, "Wind Loads: ASCE 7-10, Additional Analytical Methods."

Deleted items include seventh-edition sections 7.3.3, "Handling, Transporting, and Erecting;" 7.3.4, "Tolerances;" 7.3.6.1, "Welded-Wire Reinforcement;" 7.3.6.2, "Reinforcing Bars;" and 7.3.6.3, "Prestressing;" Fig. 7.3.7, which shows the optimum handling sequence of precast concrete units; Fig. 7.3.8, which shows hoisting and rotating multistory units; Fig. 7.6.1, which shows relative temperature, creep, and moisture movements of concrete, brick, tile, and mortar; and Fig. 7.6.2, which shows typical stone-veneer anchors; and Table 7.6.4, "Ultimate Shear Capacity of Spring Clip [Hairpin] in Granite." Also, section 7.6, "Clay-Faced and Stone Veneers," has been condensed considerably, with several references added that direct users to more up-to-date information.

Chapter 8—Component Handling and Erection Bracing

A new Fig. 8.2.3, which shows riser lifting, includes a rigging diagram for a double stadium riser unit. Section 8.3.3, "Spreader Beam," has been condensed.

Section 8.3.5.2, "Prestressing-Strand Loops," changes the highest recommended strand lift loop capacity from 8 to 10 kip. This change takes us back to the value given in the fourth edition, published in 1992. The committee determined that a 10 kip capacity still provides the required factor of safety of 4 and is based on the experience of those using strand lift loops.

Figure 8.3.11, which shows a swivel plate, was significantly revised to clarify the forces acting on the swivel plate system.

Section 8.6, "Erection Handling," and Fig. 8.6.1 were expanded to emphasize the perils of uncontrolled panel rolling during rotation to vertical during erection, as well as possible stress reversals.

Example 8.7.1, "Erecting a Single-Story Industrial Building," is new. Of note, wind loads are based on ASCE 7-10 chapter

29 for loads on freestanding walls and signs, and aboveground concrete deadmen are used to react against the braces.

Section 8.7.2, "Responsibilities," contains significant clarifications related to erection stability.

Chapter 9—Precast and Prestressed Concrete: Materials

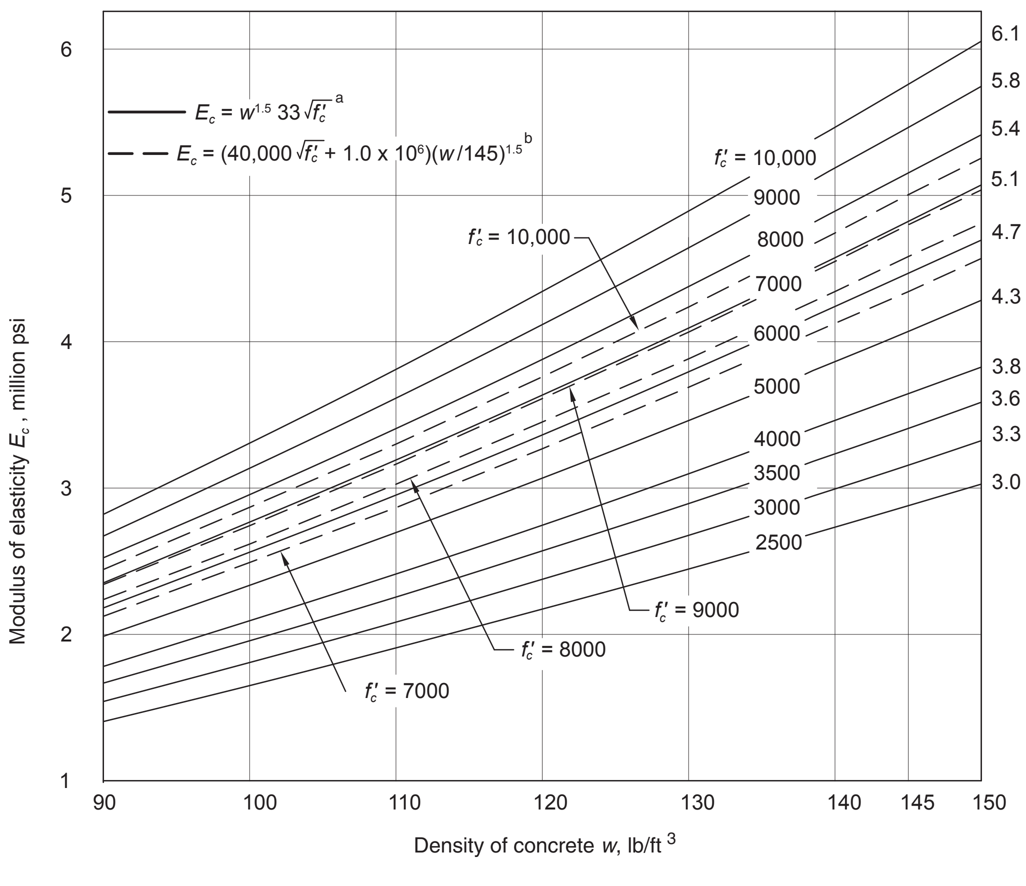
This chapter was reorganized to flow from materials internal to the component (concrete, reinforcement) to connections (grout, connection materials) to coatings and other considerations. Corrosion and protection of reinforcement (internal) was separated from corrosion and protection of connections (external). In addition, there is expansion and clarification of seventh-edition material. The chapter was reviewed by the PCI Concrete Materials Technology Committee before the Industry Handbook Committee ballot.

Specific updates within this chapter include the following.

Section 9.2, "Concrete," has added descriptions of types and uses of concrete (high-performance concrete, lightweight concrete, self-consolidating concrete, and fiber-reinforced concrete). Section 9.2.1.3, "Aggregates," has expanded information on durability of aggregates in concrete. Section 9.2.1.4, "Chemical Admixtures," has expanded information on chemical admixtures for concrete.

Section 9.2.2, "Fresh Concrete Properties," is new and includes subsections on slump, air content, workability, and curing.

Section 9.2.3, "Hardened Concrete Properties," was expanded, including Fig. 9.2.4, which shows the concrete modulus of elasticity as affected by concrete density and strength (**Fig. 15**) and was moved from seventh-edition Design Aid 15.2.1. Seventh-edition Tables 9.2.3, "Aggregate Size and Gradation



Note: compressive strength values are shown in psi.

a. Alternatively, ACI 318-14 allows use of $E_c = 57{,}000\sqrt{f'_c}$ for normalweight concrete.

b. These curves for E_c comply with comply with ACI 363R-10[14].

Figure 15. Concrete modulus of elasticity as affected by concrete density and strength.

Limits from ASTM C33 and D448," and 9.2.8, "Coefficients of Linear Thermal Expansion of Rock [Aggregate] and Concrete," have been deleted. Deterioration mechanisms are now separated into external sources, section 9.2.3.6, "Durability," and internal sources, section 9.2.3.7, "Reactivity."

Figure 9.2.7, which shows the relationship of creep with time (**Fig. 16**), is significantly changed from the seventh edition. The seventh edition showed a general relationship of creep over time, including recoverable and irreversible creep. The eighth edition shows the results of a laboratory study of creep and creep recovery for normal- and high-strength concretes loaded at initial stress levels of 40% and 70% of the initial concrete compressive strength.

Section 9.3.1, "Prestressing Tendons," was expanded, including a new Fig. 9.3.3, which shows steps to manufacture prestressing strand. New section 9.3.1.1, "Strand Bond," provides information on testing strand for bond characteristics.

Section 9.5.3, "Structural Bolts/Anchor Bolts," now contains discussion and caution on the welding of structural bolts, anchor bolts, nuts, and washers due to chemical composition and heat treatments.

Section 9.5, "Connection Materials," has expanded discussion on connection robustness, corrosion (including galvanic corrosion), and protection.

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

This chapter has seen only minor updates from its seventh-edition version. One item of note concerns the definitions of concrete types based on density. The bottom end of the lightweight concrete range was extended by 5 lb/ft^3 so that it now covers 90 to 105 lb/ft^3 densities. Normalweight concrete is now defined as anything more dense than 120 lb/ft^3, and sand-lightweight concrete is defined as that between 105 lb/ft^3 and 120 lb/ft^3. Previously, normalweight concrete was defined as "approximately 150 lb/ft^3," which left many concrete densities between values. It is interesting to note that these concrete definitions differ from the definitions for the remainder of the handbook provided in chapter 9 (and ACI 318-14). This is because the definitions in chapter 10 date back to when much of the fire testing of concrete components was going on, so they remain thus in PCI MNL-124,[35] which is the source document for most of the information in this chapter.

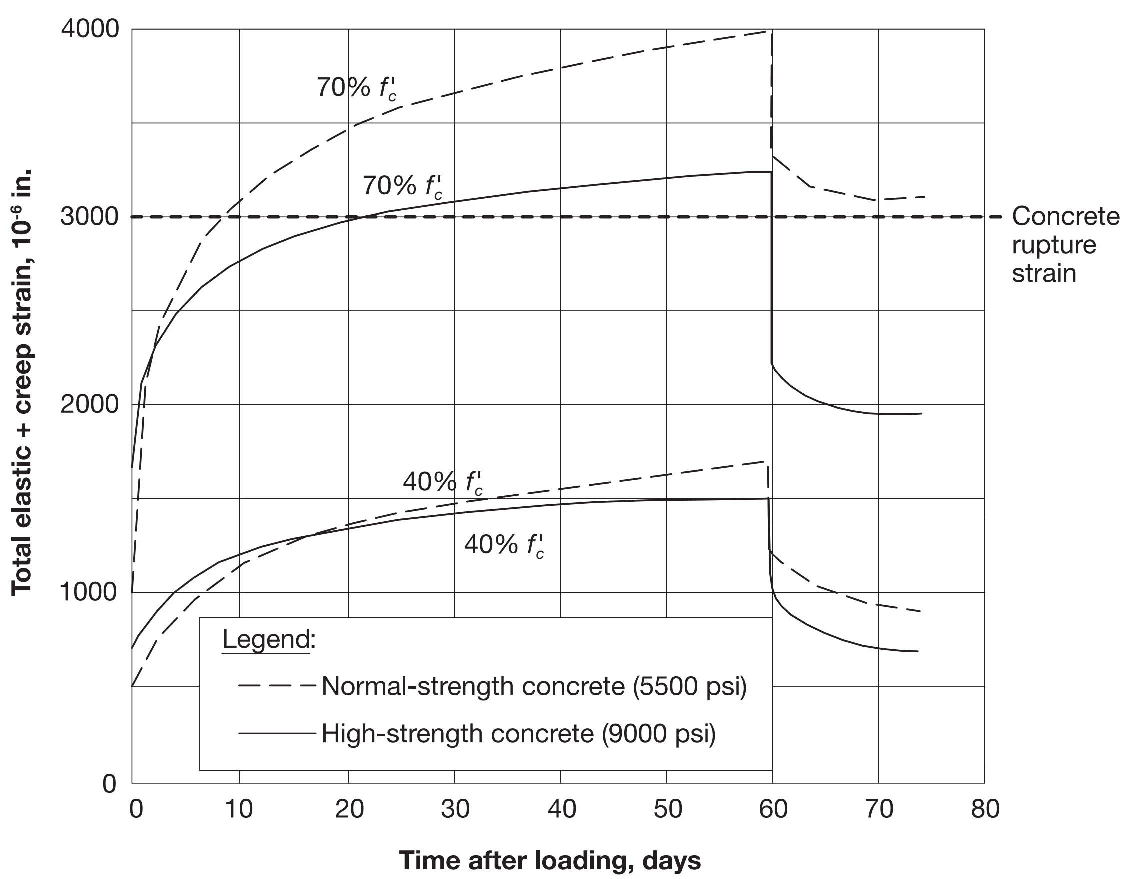


Figure 16. Relationship of creep with time. Source: Adapted from M. M. Smadi, F. O. Slate, and A. H. Nilson, "Shrinkage and Creep of High-, Medium-, and Low-Strength Concretes, Including Overloads," *ACI Materials Journal* 84 (3) (1987, Fig. 8 and 9): 224–234.

Several values of fire endurance in Table 10.5.5, "Fire Endurance of Precast Concrete Sandwich Walls Based on Eq. 10-2," have been modified as a result of a more intensive study by members of the Industry Handbook Committee.

Chapter 11—Thermal and Acoustical Properties of Precast Concrete

Only minor updates were made to this chapter.

Chapter 12—Vibration Design of Precast/Prestressed Concrete Floor Systems

Only minor changes were made to this chapter. Most notable among them are that the term *natural frequency* is now *fundamental frequency*; the equations in section 12.4.1, "Computing the Fundamental Frequency," were rearranged to flow better; and a new section 12.11, "Damping Devices for Precast Concrete Structures," was added to remind the designer that there are other options available when the design objectives for vibration control cannot be achieved by varying mass and stiffness alone and to provide some general information on these specialized systems.

Chapter 13—Tolerances for Precast and Prestressed Concrete

The changes to this chapter were minor. A few clarifications and graphic corrections were made. Also, a definition was added for *primary control surface* in the definitions section, and ACI ITG 7-09, *Specification for Tolerances for Precast Concrete*,[36] which is ACI's tolerance document that basically follows PCI MNL 135-00, was added as a reference.

Chapter 14—Specifications and Standard Practices

Of note, the roles and responsibilities of the SER, also referred to as the engineer of record, and the SSE, also referred to as the precast engineer, have been defined. Otherwise, updates are of a minor nature: some organizational revisions as well as some terminology revisions for consistency within this handbook and with ACI.

The PCI standard design practice for ACI 318-14 was still under development by the PCI Building Code Committee at the time of publication of the eighth edition, so it is not included in this chapter. When available, it will be published in *PCI Journal* and made available on the PCI website.

Seventh-edition sections 14.2, "Guide Specification for Structural Precast Concrete and Structural Precast Concrete with Commercial Architectural Finish," and 14.3, "Guide Specification for Architectural Precast Concrete," do not appear in the eighth edition because they directed the user to a companion CD. Now those guide specifications are available in the form of an editable Microsoft Word document available on the PCI website under "Guide Specifications" in the "Design Resources" section.

Chapter 15—General Design Information

In addition to code updates, minor clarifications, and graphical modifications, the following changes were made.

Several seventh-edition design aids were moved or removed. Design Aid 15.2.1, "Concrete Modulus of Elasticity as Affected by Concrete Density and Strength," was moved to chapter 9 and Design Aids 15.4.5, "Bar Area Equivalents in a 1-Foot-Wide Section," and 15.9.4, "Concrete Stress Coefficients," were deleted as unnecessary due to the widespread use of calculators and computers.

In Design Aid 15.1.1, "Dead Weights of Floors, Ceilings, Roofs, and Walls," some corrections were made to the concrete masonry unit wall wythe weights. Design Aid 15.1.2, "Recommended Minimum Uniformly Distributed and Concentrated Live Loads," was revised to match IBC 2015. Several formulas were corrected in Design Aid 15.1.3, "Beam Design Equations and Diagrams."

The information on three- and four-wire strand was deleted from Design Aid 15.2.1, "Properties and Design Strengths of Prestressing Strand and Wire," because these are seldom used in current construction. Also, the jacking forces for various fractions of f_{pu} have been deleted because they are easily determined with a calculator.

Design Aid 15.5.2, "Dimensions of Standard Washers," was completely overhauled, and Design Aid 15.5.3, "Recommended Nuts and Washers for Bolts and Threaded Rods," is new.

In Design Aid 15.6.2, "Typical Welded Joints in Precast Concrete Construction," two joint details were replaced by more commonly used ones.

Appendix A—Blast-Resistant Design of Precast, Prestressed Concrete Components

This appendix replaces section 4.9, "Blast-Resistant Design of Precast, Prestressed Concrete Components," of the seventh edition. It is essentially the work of the PCI Blast Resistance and Structural Integrity Committee condensed from its *Blast-Resistant Design Manual*[37] and published preliminarily in *PCI Journal* as "*PCI Design Handbook*: Appendix A: Blast-Resistant Design of Precast, Prestressed Concrete Components."[38]

Considerably expanded from the seventh-edition version, users will now find lists of definitions, notation, and references. New sections A.6, "Connection Demands due to Blast Loads;" A.7, "Energy Methods to Determine Approximate Displacement;" and A.8, "Special Considerations for Insulated Non-load-bearing Wall Panels," provide important design information. To illustrate some of these added concepts, two new examples are provided: Example A.2, "Reaction Design Example," and A.3, "Sandwich Panel Resistance Example." **Figure 17** shows possible sandwich panel shear tie layouts as covered in Example A.3.

Appendix B—Design for Structural Integrity and Disproportionate Collapse

Most of the information in section 4.3, "Structural Integrity," of the seventh edition was moved to this new appendix. A comparison of the tables of contents of seventh-edition section 4.3 with eighth-edition appendix B (**Fig. 18**) provides users with a feel for the magnitude of the expansion of material on structural integrity and disproportionate collapse.

Section B.3.6, "Case Study Structure," provides a primer for approaching the disproportionate collapse issue for a real-world building (**Fig. 19**).

Also of note is that seventh-edition Example 4.3.2.1, "Compliance of a Precast Concrete Structure with Structural Integrity Provisions," has been replaced by Example B.5.1, "UFC Tie-Force Requirements." UFC refers to Unified Facilities Criteria 4-023-03, *Design of Buildings to Resist Progressive Collapse*.[39]

Appendix C—Precast Concrete Diaphragm Design in Accordance with Alternative Provisions of ASCE 7-16

This appendix presents diaphragm design provisions that are now incorporated into ASCE 7-16[40] (and will be adopted by reference into IBC 2018) along with background information. The new section in ASCE 7-16 is section 12.10.3, "Alternative Design Provisions for Diaphragms Including Chords and Collectors," which is required for precast concrete diaphragms in structures assigned to seismic design categories (SDCs) C and higher. This alternative procedure is optional for precast concrete diaphragms in SDC B and cast-in-place concrete diaphragms.

These provisions are based on the DSDM research sponsored by the Charles Pankow Foundation, the National Science Foundation, and PCI.[41] Current acceptance criteria ICC Evaluation Service (ICC-ES) AC468[42] and evaluation report ICC-ES ESR-3010[43] allow for the use of this methodology before adoption of IBC 2018.

Under this procedure, the diaphragm force is proportional to diaphragm design acceleration coefficient C_{px} and inversely proportional to diaphragm design force-reduction factor R_s. Detailed instructions for determining these coefficients are provided. It is interesting (though not surprising) to note that ductility of the connections (or joint reinforcement) plays an important role in the force-reduction factor, and guidelines for classifying of a connection by ductility are provided.

The appendix concludes by providing a six-step procedure for precast concrete diaphragm design by ASCE 7-16 section 12.10.3.

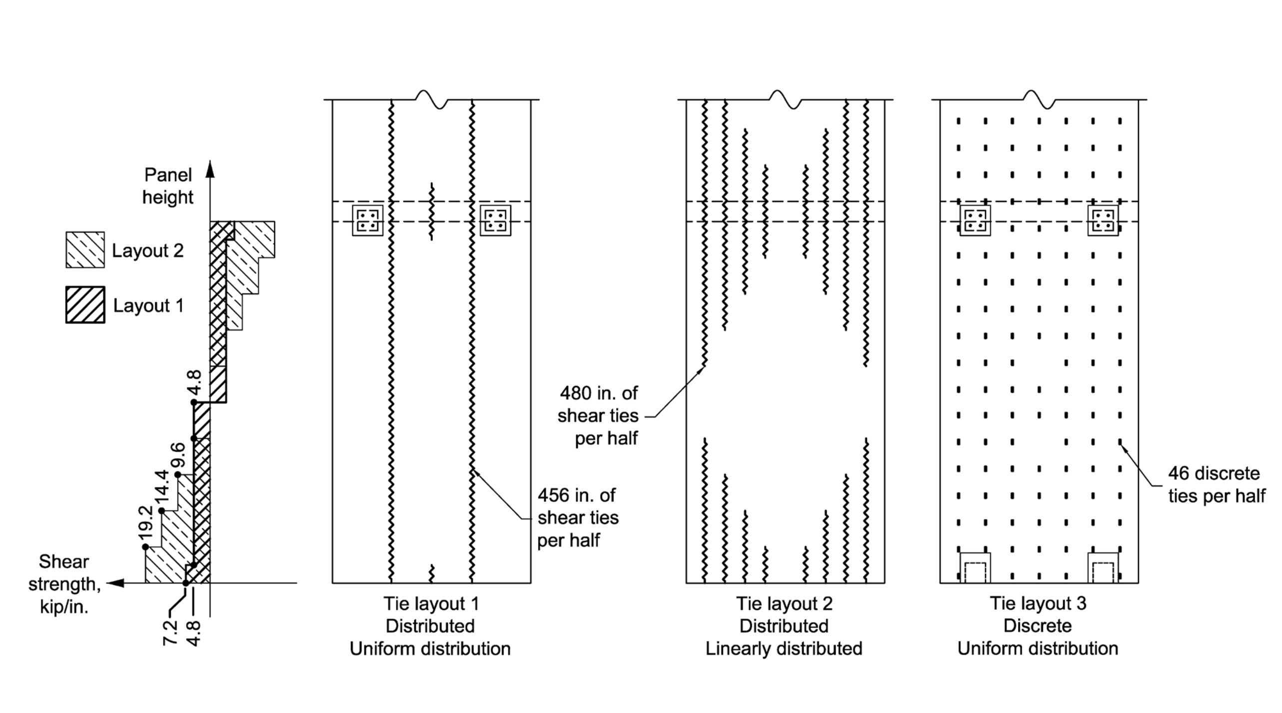


Figure 17. Possible shear tie layouts.

7th Ed. from Chapter 4 TOC:

4.3 Structural Integrity
4.3.1 Introduction
4.3.2 Precast Concrete Structures
4.3.3 Large-Panel Bearing-Wall Structures
4.3.4 Structures with Mixed Structural Materials

8th Ed. Appendix B TOC:

B.1 Introduction
B.2 Historical Development of Structural-Integrity Requirements
B.3 Design Approaches for Structural Integrity and Disproportionate-Collapse Resistance
B.4 Building-Code Criteria for Structural Integrity
B.4.1 ASCE 7-10
B.4.2 ACI 318-14 Structural-Integrity Provisions
B.5 UFC 4-023-03 Unified Facilities Criteria: Design of Buildings to Resist Progressive Collapse
B.6 GSA Progressive-Collapse Analysis and Design Guidelines for New Federal Office Buildings and Major Modernization Projects
B.7 Design Strategies for Precast Concrete to Resist Disproportionate Collapse
B.8 References

Figure 18. Tables of contents comparison.

Conclusion

Most of the goals established by the PCI Industry Handbook Committee for the eighth edition have been accomplished. However, implementation of many less-critical topics and suggested changes, including some raised during the blue-ribbon review, was postponed because of timing and publishing constraints. The committee has gathered these items for future consideration and has provided them to the next PCI Industry Handbook Committee, to be chaired by Jared Brewe.

As stated in the 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 to IHBErrata@pci.org.

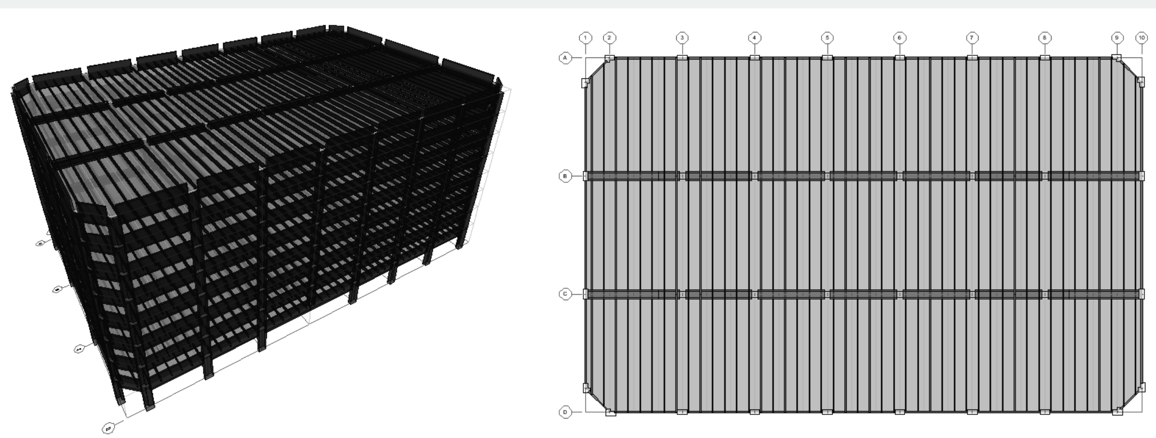


Figure 19. Disproportionate collapse case study structure.

Postpublication notes

The name of a consulting member of the Industry Handbook Committee, Kim Seeber, PE, FPCI, was accidentally left off of the list of members in the front of the handbook. The committee regrets this omission.

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