An Introduction to

Section-5 Reorganization

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Organization

- Pool Fund project – KS lead, IA, MI,NJ, OH, UT
- Oversight
  - T-10 (KS, ID, PA, NH, LA, TN, VA, TX, MN, NE, WI, CA, OR, FL, WA)
  - FHWA – Reggie Holt, Dr. Joey Hartman
  - Industry Liaison: PCI, ASBI
  - Others invited as needed
- Contractor: MM with Dr. Mertz

Scope

- Survey Stake Holders
- Critically Review Past Interims
- Develop Annotated Revised TOC
- Develop New Revised and Reorganized Draft Section 5
- Finalize for Consideration by T-10 and SCOBS.

Process

- Survey
- Outline showing broad reorg
- So far:
  – 6 Drafts reviewed so far
  – 5 Working meetings with Augmented T-10
  – About a thousand comments received on Drafts.

Major Decisions Following Survey

- Evolution, not Revolution
- Keep current units
- Advance Disturbed Regions (Strut & Tie)
- Keep current Bending and Axial Design
- Reduce Shear Options – Drop “Vci-Vcw”
- Consolidate Reinforcing Details, Prestressing Details, & Seismic in 3 Separate Articles
- Harmonize Shear and Torsion if Possible

Major Decisions

- Simplify/reduce significant figures of constants used in specification.
- Attempt to have topics and procedures appear once within the body of Section 5.
- Appendices can be used in reorganization.
- Reference proprietary materials by their ASTM.
- Organize Section 5 articles such that more common design provisions come before unique design provisions.
- Use the term nonprestressed reinforcement instead of mild steel/reinforcement

Schedule

2016 agenda item to replace Section 5

- Final Pooled Fund review meeting held in Austin in August
- Final draft version provided to T-10 in September
- SCOBS Draft Ballot Item went out on October 1st
- T-10 Host webinar October 21st (today!) to discuss in more detail
- SCOBS Comments are due back by December 1st.
- Will be included in “normal” SCOBS review

The Big Picture

- Largely unchanged, but updated as needed:
  - 5.1 Scope (Introduce B-Region/D-Region Concept)
  - 5.2 Definitions
  - 5.3 Notation
  - 5.4 Material Properties (some deletions)
  - 5.5 Limit States and Design Methodologies (New articles to define B-Regions and D-Regions)

The Big Picture

- 5.6 (5.7) Design for Flex and Axial Force Effects – B-Regions
  - Largely unchanged except applicability to D-Regions
  - P/S and R/C
- 5.7 (5.8) Shear and Torsion – B-Regions
  - P/S and R/C
  - Two fewer methods in the section
    - “V_{ci}-V_{cw}” removed (5.8.3.4.3)
    - Segmental moved to 5.12.5 (5.8.6)
  - Principal tension check moved to 5.9.2.3.3 (5.8.5)

The Big Picture

- 5.8 (5.6) Design of D-Regions
  - STM provisions from 2016 interim revisions
    - Design of General Zones by STM (5.10.9.4)
  - Elastic Analysis (5.10.9.5)
  - Approximate Stress Analysis and Design (legacy methods from 5.10.9.6)
    - Deep beams
    - Brackets and corbels
    - Beam ledges

The Big Picture

- 5.9 (5.9) Prestressing
  - Better separation of pre and post
  - Pieces from 3 sections (5.9, 5.10, 5.11)
    - 5.9.1 General
    - 5.9.2 Stress Limitations (Incl Principal stress)
    - 5.9.3 Prestress Loses
    - 5.9.4 Pretensioning
    - 5.9.5 Post-tensioning

The Big Picture

- 5.10 (5.10) Reinforcement
  - only R/C
  - Pieces from 2 sections: 5.10 and 5.11
  - Cover in 5.10.1, not 5.14
- 5.11 (5.10.11) Seismic Design and Details
  - now includes some provisions for piles
  - Made more prominent in hierarchy
  - Seismic hooks still in 5.10.2.2

The Big Picture

- 5.12 (5.13) Provisions for Structure, Components, and Type
  - 5.12.1 Deck Slabs
  - 5.12.2 Slab Superstructures
  - 5.12.3 Beams and Girders
  - 5.12.4 Diaphragms
  - 5.12.5 Segmental Construction
  - 5.12.6 Arches
  - 5.12.7 Culverts
  - 5.12.8 Footings
  - 5.12.9 Concrete Piles

The Big Picture

- 5.13 (new) Anchors –Refers to ACI 318 -14, Chapter 17
  - More on this later

The Big Picture

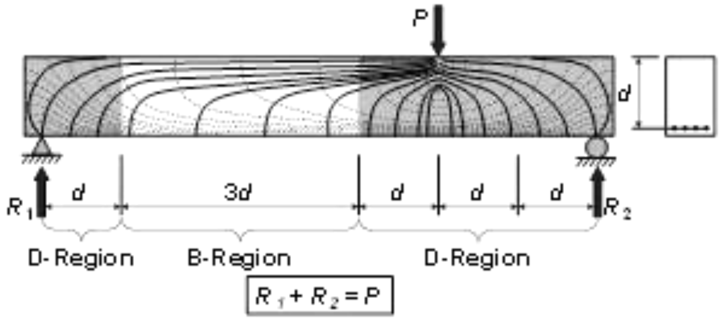
- 5.14 (5.12) Durability – existing + NCHRP, R19B
  - 5.14.1 Design Concepts
  - 5.14.2 Major Chemical and Mechanical Factors Affecting Durability
    - Corrosion Resistance
    - Freeze-Thaw Resistance
    - External Sulfate Attack
    - Delayed Ettringite Formation
    - Alkali-Silica Reactive Aggregates
    - Alkali-Carbonate Reactive Aggregates

The Big Picture

- 5.14.3 Concrete Cover – cross ref to table in 5.10.1
- 5.14.4 Protective Coatings
- 5.14.5 Protection for Prestressing Tendons
- 5.15 (5.15) References - added/updated
- Appendices - current 5 retained – updated for new organization

B- and D-Regions

- Concept introduced in Article 5.1



B- and D-Regions

- Terms defined in Article 5.2

  Beam or Bernoulli Region (B-Region)—Regions of concrete members in which Bernoulli's hypothesis of straight-line strain profiles, linear for bending and uniform for shear, applies.

  Disturbed or Discontinuity Region (D-Region)—Regions of concrete members encompassing abrupt changes in geometry or concentrated forces in which strain profiles more complex than straight lines exist.

B- and D-Regions

- Design methodologies specified in Article 5.5.1.2

  Design practices for B-Regions shall be based on a sectional model for behavior (Articles 5.6 and 5.7 for bending and shear, respectively).

  The Strut-and-Tie Method (Article 5.8.2) may be applied for the design of all types of D-Regions. The most common types of D-Regions, such as beam ends, diaphragms, deep beams, brackets, corbels and beam ledges, may be designed by the empirical legacy approaches or detailing practices (Article 5.8.4).

B- and D-Regions

- Resultant Reorganized Sub-Section

¶ 5.5 – Limit States & Design Methodologies

¶ 5.6 – Design for Flexural & Axial Force Effects – B Regions

¶ 5.7 – Design for Shear & Torsion – B Regions

¶ 5.8 – Design of D-regions

  ¶ 5.8.1 – General

  ¶ 5.8.2 – Strut and Tie Method (STM)

  ¶ 5.8.3 – Elastic Stress Analysis

  ¶ 5.8.4 – Approximate Stress Analysis & Design

What to Expect

- Global Reorg as indicated
- Most articles have some wording change that make intent clearer e.g:
  - Conditionals in ~60 locations modified
  - Use of bonded, fully bonded, partially unbonded, debonded, partially debonded, blanketed and shielded replaced with bonded, debonded and unbonded ~ 94 places
  - Consistent definition of f'_c ~ 390 places

What to Expect

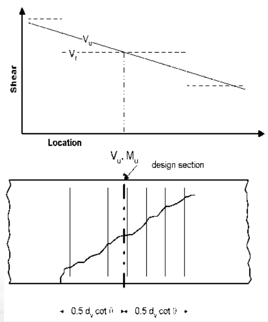
- Some articles reorged, streamlined or augmented, e.g. 5.7.4 Interface Shear
- Some individual provisions clarified or moved
- Some corrections –
  - eg combined stress in web service tension should have been in beta-theta strength calc

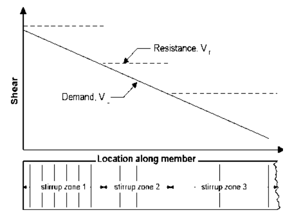
$$V_{eff} = \sqrt{V_u^2 + \left(\frac{0.9 p_h T_u}{2A_o}\right)^2}$$

$$\varepsilon_s = \frac{\left(\frac{|M_u|}{d_v} + 0.5N_u + |V_u - V_p| - A_{ps} f_{po}\right)}{E_s A_s + E_p A_{ps}}$$

What to Expect

- Some corrections – Miss-located info
  - e.g. Stirrup spacing commentary in article that did not deal with stirrups - relocated





What to Expect

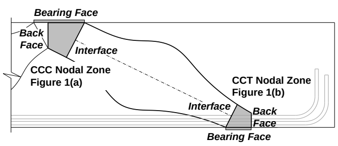
- Some corrections – Some orphans removed
  - e.g. 5.8.4.1 Deep Beams

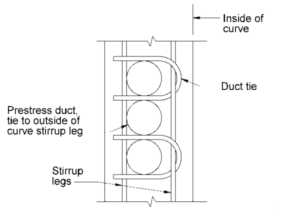
$$N_R = \phi f_y A_s \geq 0.12 b_v s$$

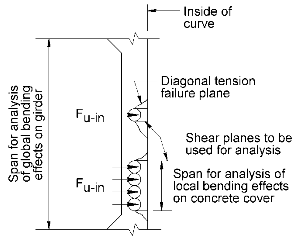
This did not make any sense where it was and effectively duplicated the crack control requirements in 5.8.2.6 in strut and tie articles. Replaced with cross ref to STM crack control and better info of requirements for legacy methods for deep beams.

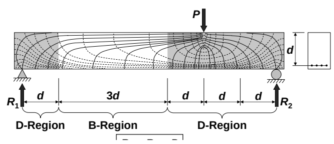
What to Expect

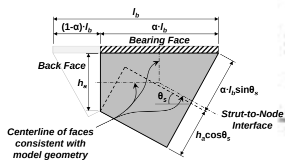
- Some new/modified figures

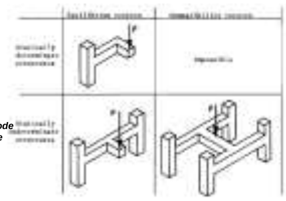


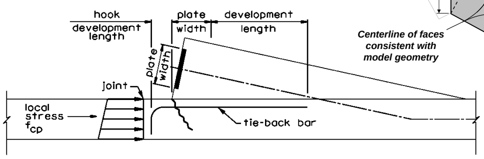






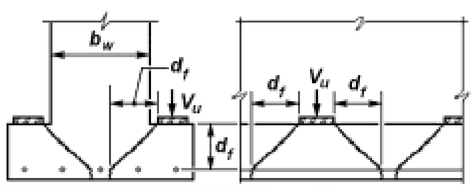


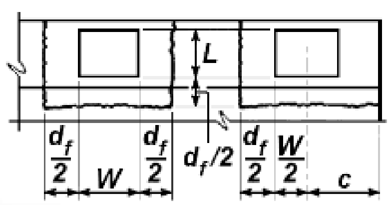




In-Progress WAIs Included in Reorg

- WAI 182 - Strut and Tie Method – 2015 Agenda Item – replaced WAI 153
- WAI 130 – obviated by shear changes
- WAI 169 - 12 updates for corbels, beam ledges and inverted T caps





Revisions to Beam Ledges

- Summary of changes
  - Definition of depth: d_e to d_f
  - Definition width: b_w to b
  - Shear perimeter, b_o introduced to prevent punching shear overlap and include circular bearing pads

Punching Shear in Beam Ledges (New 5.8.4.3.4, Old 5.13.2.5.4)

Between bearings on opposite ledges of an inverted T-beam web:

$$b_w + 2a_v > L + 2d_f \qquad (5.8.4.3.4\text{-}1)$$

Between adjacent bearings:

Prevent Overlap

$$S > 2d_f + W \qquad (5.8.4.3.4\text{-}2)$$

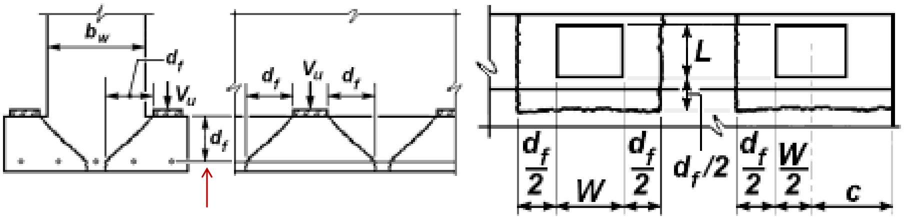
Any ledge

where:

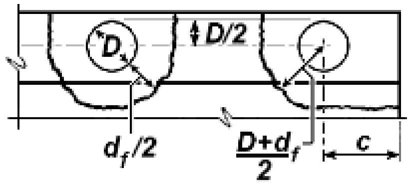
Important definition

b_w = the width of the inverted T-beam stem (in.)
a_v = distance from face of wall to the concentrated load (in.)
L = length of bearing pad (in.)
d_f = distance from top of ledge to the bottom longitudinal reinforcement (in.)
S = center-to-center spacing of bearing along a beam ledge (in.)
W = width of bearing plate or pad (in.)

Truncated Pyramids – Inverted T-Caps



d_f = distance from top of ledge to bottom steel – used to project Punching shear pyramid



$$V_n = 0.125\lambda\sqrt{f'_c}b_o d_f$$

Shear Perimeter

Shear Perimeter to Prevent Overlap

At interior rectangular pads:

$$b_o = W + 2L + 2d_f \qquad (5.8.4.3.4\text{-}4)$$

At exterior rectangular pads:

$$b_o = 0.5W + L + d_f + c \leq W + 2L + 2d_f \qquad (5.8.4.3.4\text{-}5)$$

At interior circular pads:

$$b_o = \frac{\pi}{2}\left(D + d_f\right) + D \qquad (5.8.4.3.4\text{-}6)$$

At exterior circular pads:

$$b_o = \frac{\pi}{4}\left(D + d_f\right) + \frac{D}{2} + c \leq \frac{\pi}{2}\left(D + d_f\right) + D \qquad (5.8.4.3.4\text{-}7)$$

Hanger Reinforcement

- Hanger reinf …provided in addition to the ~~lesser~~ shear reinf on either side of bean…
- Nominal shear resistance ~~for single beam ledges~~ shall be taken as:
- Equations for strength and service limit states are the same but there are limits on (W+3a_v) and S that can be used

Nominal Shear Reistance of Ledges on Inverted T-Caps

- Equation for Vn is the same, BUT
  - The new definition of d_f is used
  - Definition for b_f added—still as shown in associated figure

Corbels

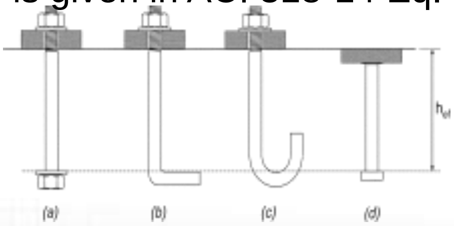
- Correction of width from web width, b_w, to width of corbel, b.
- Other symbol inconsistency clean up.

Article 13 Anchors

- Linked to ACI 318-14, Chapter 17 with some exceptions
- Article 13 intended to provide guidance on types of anchor covered, design conditions that may need to be investigated, and modifications and applications specifics.

Cast-in-Place Anchors

- Headed studs and headed bolts;
- Hooked bolts having a geometry that has been demonstrated to result in a pullout strength without the benefit of friction in uncracked concrete equal to or exceeding $1.4N_p$, where N_p is given in ACI 318-14 Eq. 17.4.3.5;

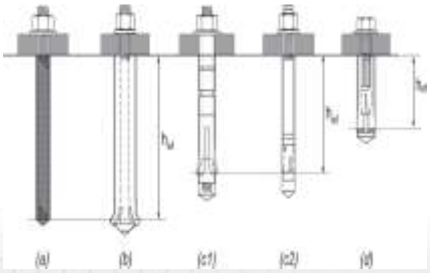


(a) hex head bolt with washer
(b) L-bolt
(c) J-bolt welded
(d)headed stud

Source: ACI 318-14

Post-Installed Anchors

- Expansion and undercut anchors meeting the assessment criteria of ACI 355.2 (2007), and;
- Adhesive anchors meeting the assessment criteria of ACI 355.4 (2011).

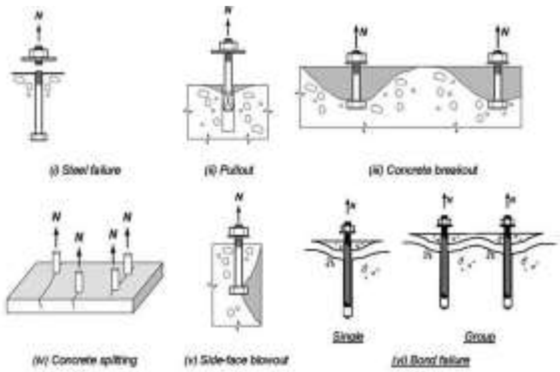


(a) adhesive anchor;
(b) undercut anchor;
(c) Torque-controlled expansion anchors (c-1) sleeve-type and (c2) stud type; and
(d) drop-in type displacement controlled expansion anchor

Source: ACI 318-14

Failure Modes - Tension

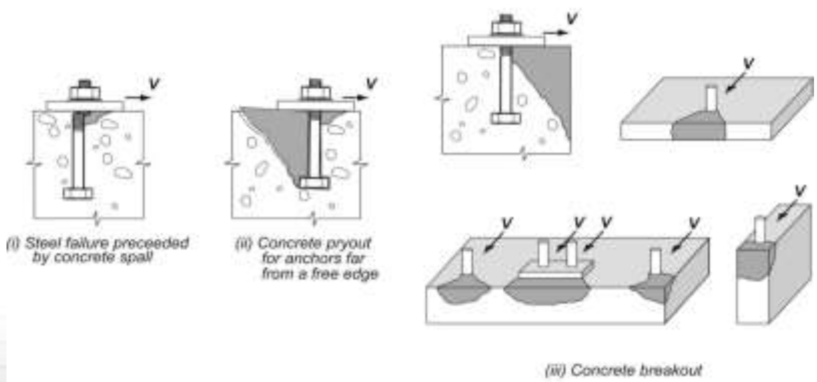
- Tensile strength of anchor steel
- Concrete breakout – all types
- Pullout – CIP, post installed expansion and undercut
- Side-face blowout – headed anchors
- Bond failure – adhesive anchors



Source: ACI 318-14

Failure Modes - Shear

- Shear strength of anchor steel
- Concrete breakout – all types
- Pryout – all types



Failure mode	Single anchor	Anchor group[1]	
		Individual anchor in a group	Anchors as a group
Steel strength in tension (17.4.1)	$\phi N_{sa} \geq N_{ua}$	$\phi N_{sa} \geq N_{ua,i}$	
Concrete breakout strength in tension (17.4.2)	$\phi N_{cb} \geq N_{ua}$		$\phi N_{cbg} \geq N_{ua,g}$
Pullout strength in tension (17.4.3)	$\phi N_{pn} \geq N_{ua}$	$\phi N_{pn} \geq N_{ua,i}$	
Concrete side-face blowout strength in tension (17.4.4)	$\phi N_{sb} \geq N_{ua}$		$\phi N_{sbg} \geq N_{ua,g}$
Bond strength of adhesive anchor in tension (17.4.5)	$\phi N_{a} \geq N_{ua}$		$\phi N_{ag} \geq N_{ua,g}$
Steel strength in shear (17.5.1)	$\phi V_{sa} \geq V_{ua}$	$\phi V_{sa} \geq V_{ua,i}$	
Concrete breakout strength in shear (17.5.2)	$\phi V_{cb} \geq V_{ua}$		$\phi V_{cbg} \geq V_{ua,g}$
Concrete pryout strength in shear (17.5.3)	$\phi V_{cp} \geq V_{ua}$		$\phi V_{cpg} \geq V_{ua,g}$

Factored Resistance ≥ Factored loads

There are caveats

Source: ACI 318-14

Nominal Resistance

- Cast-in-place:
  - By calculation procedures in ACI 318-14, Chapter 17
  - 5% fractile using test methods specified in ACI 355.2
- Post Installed
  - 5% fractile based on ACI 355.4
  - For adhesive anchors for which test data is not available at design there is a table of presumptive minimum characteristic bond stresses – need adjustments for sustained loading and seismic design

Impact Loads

- Excluded from ACI 318 – 14
- For AASHTO:
  - Anchors for ped or bicycle rails or fences separated from roadway not subject to exclusion
  - Attachments using post-installed anchors show to have documented impact strength greater than their static strength, deemed acceptable to owner OK for impact loads.
  - Use of documented Dynamic Increase Factors is at owner's discretion

Impact loads

- ACI 349 – 13 no longer requires impact exclusion for nuclear facilities
- Literature has many examples of impact strength > static – e.g. MwRSF report TRP-13-264-12

Source: MwRSF TRP 13-264-12

Loads and Resistance Factors

- Loads and load factors from Section 3 of AASHTO LRFD
- Resistance factors from “strength reduction factors” in ACI 318-14
- Usually we try not to “mix and match” from different specifications
- But in this case it was probably slightly conservative to proceed as indicated for this first application in AASHTO LRFD

Sustained Tension

- Factored resistance further reduced by factor of 0.50 for significant sustained tensile load
- ACI uses 0.55 – suggests less for design life > 50 yrs
- Lower factor recommended by Cook et al in NCHRP 757
  - 100 years at 70 deg F
  - 20 years at 110 deg F
- “Significant” ???? OrDOT has been using 10% of ultimate capacity as limit of unfactored load

Seismic Design

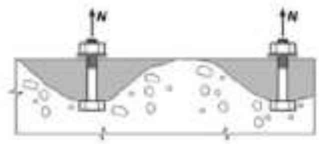
- Despite use of different return period maps (5000 yr vs 1000 yr) there are scaling factors that bring ACI (ASCE/SEI 7) closer together than seen at fist glance.
- Site factors same but entry point into tabular data is different
- But – comparison shows that AASHTO SZ 1 reasonable represents ASCE SEI SDCs A and B
- ACI makes no distinction among requirements for other SDC’s – so Article 13 make no distinction among SZs B, C or D

Seismic Design

- Anchors resisting seismic forces must be suitable for cracked concrete – ACI 355.2 and 355.4 have simulated seismic tests for expansion, undercut and adhesive anchors.
- Design provisions do not apply in plastic hinge zones
- Anchor reinforcement must carry loads to body of member

A Sample of ACI Provisions

- Previously: Failure Modes in Tension
  - Tensile strength of anchor steel
  - Concrete breakout – all types



  - Pullout – CIP, post installed expansion and undercut anchors
  - Side-face blowout – headed anchors
  - Bond failure – adhesive anchors

Nominal Strength

- Method must result in substantial agreement with test results – 5% fractile basic individual anchor strength
- Developed from Concrete Capacity Design Method
- When strength related to f'_c, modify for:
  - Size effects
  - Number of anchors
  - Spacing, depth and edge distances
  - Eccentricity
  - Cracking
  - Lightweight concrete

Typical Resistance Equation

- Lots of equations and factors
- Example – Breakout strength in tension
  - For a single anchor

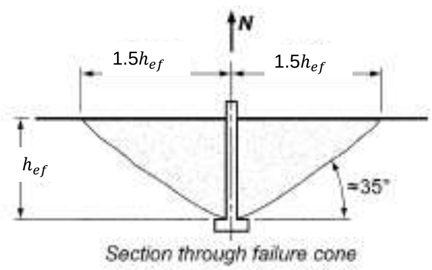
$$N_{cb} = \frac{A_{Nc}}{A_{Nco}} \varphi_{ed,N} \varphi_{c,N} \varphi_{xp,N} N_b$$

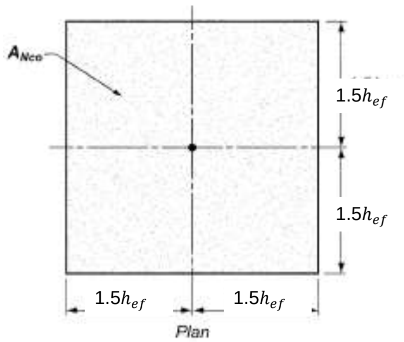
  - For a group of anchors

$$N_{cbg} = \frac{A_{Nc}}{A_{Nco}} \varphi_{ec,N} \varphi_{ed,N} \varphi_{c,N} \varphi_{xp,N} N_b$$

Source: ACI 318-14

Projected Area for Single Anchor, A_{Nco}



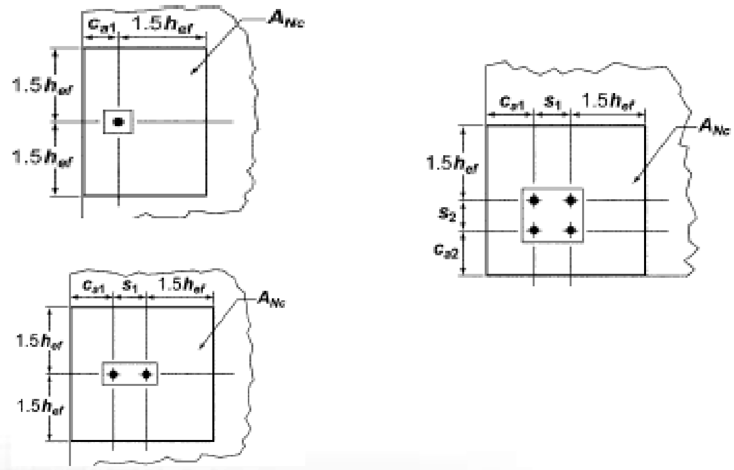


$$A_{Nco} = (2x1.5h_{ef})x(2x1.5h_{ef})$$

$$A_{Nco} = 9{h_{ef}}^2$$

Source: ACI 318-14

Projected Area for Group and Edge Distances, A_{Nc}



Source: ACI 318-14

Basic Breakout Strength – Cracked concrete

Generally:

$$N_b = k_c \lambda_a \sqrt{f'_c}\, h_{ef}^{5/3}$$

Where:
k_c = 24 for CIP anchors; and
k_c = 17 for post installed anchors

Additional possibilities for Post-Installed

However, for CIP headed studs and headed bolts with 11 in. ≤ h_{ef}≤25 in.,:

$$N_b \le 16 \lambda_a \sqrt{f'_c}\, h_{ef}^{5/3}$$

Source: ACI 318-14

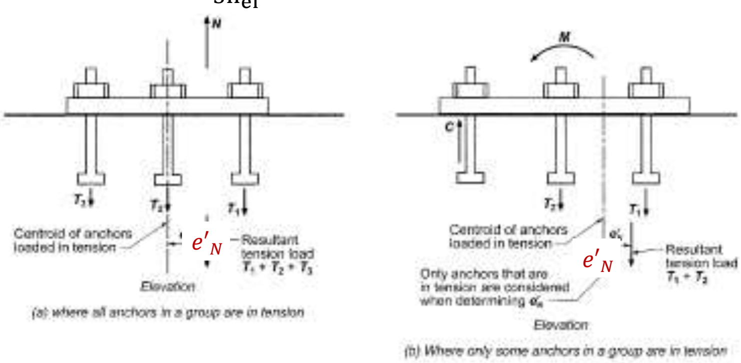
Lightweight Factor, λa

- Not same as Article 5.4.2.8
- Factors given for:
  - Cast-in-place and undercut concrete failure
  - Expansion and adhesive concrete failure
  - Adhesive anchor bond failure

Eccentricity Factor for Groups

$$\varphi_{ec,N} = 1/(1 + \frac{2e'_N}{3h_{ef}})$$

But not >1.0



e'_N Resultant of tensile anchors relative to applied load

Source: ACI 318-14

Factor for Edge Effects

If $C_{a,min} \geq 1.5h_{ef}$ then $\psi_{ed,N} = 1.0$

If $C_{a,min} \leq 1.5h_{ef}$ then $\psi_{ed,N} = 0.70 + 0.3\frac{C_{a,min}}{1.5h_{ef}}$

$C_{a,min}$ = minimum edge distance

Factor for Cracked/Uncracked Concrete

If uncracked at service load:

$\psi_{c,N}$ = *1.25* for CIP anchors; and

$\psi_{c,N}$ = *1.40* for post-installed anchors

For cracked concrete, $\psi_{c,N} = 1.00$

Many exceptions and caveats!

Factor for Uncracked Concrete

Post-Installed in uncracked but W/O supplementary reinforcement:

If $C_{a,min} \geq C_{ac}$ then $\varphi_{cp,N}$=1.0

If $C_{a,min} < C_{ac}$ then $\varphi_{cp,N}=\frac{C_{a,min}}{C_{ac}}$

Otherwise, including CIP, use 1.0

Factored Resistance

c) Anchor governed by concrete breakout, side-face blowout, pullout, or pryout strength

	Condition A	Condition B
i) Shear loads	0.75	0.70
ii) Tension loads		
Cast-in headed studs, headed bolts, or hooked bolts	0.75	0.70

Condition A applies where supplementary reinforcement is present except for pullout and pryout strengths.

Condition B applies where supplementary reinforcement is not present, and for pullout or pryout strength.

Factored Resistance

Post-installed anchors with category as determined from ACI 355.2 or ACI 355.4

Category 1 (Low sensitivity to installation and high reliability)	0.75	0.65
Category 2 (Medium sensitivity to installation and medium reliability)	0.65	0.55
Category 3 (High sensitivity to installation and lower reliability)	0.55	0.45

Source: ACI 318-14

Sources of Design Examples

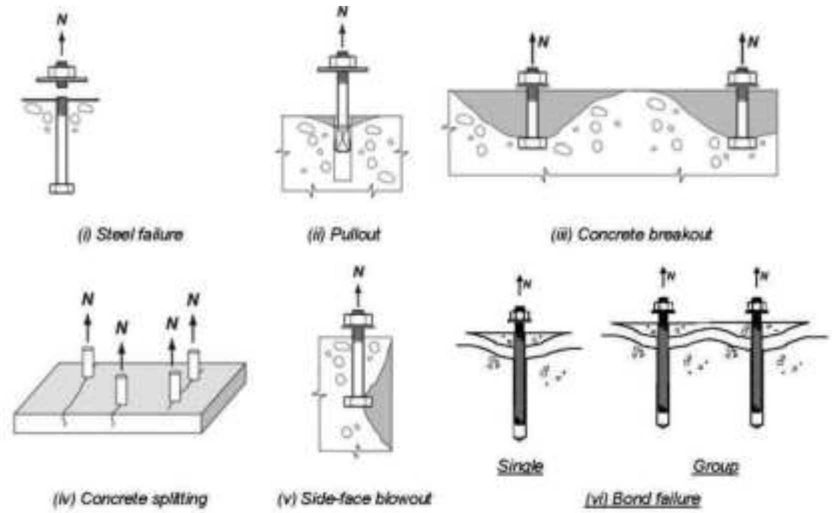
- Most of these sources are a little out of date, but can serve as a general outline of calculation procedures
  - NCHRP 757 – adhesive anchors
  - PCI Handbook – cast-in-palace anchors
  - PCA Notes on 318-11
  - Florida DOT Design Manual
  - ACI 355 R – cast-in-place and post installed but with outdate resistance factors

Summarizing

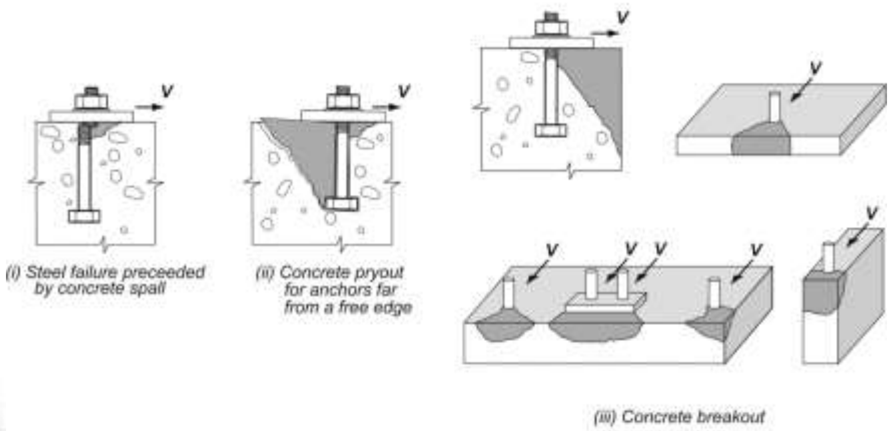
- Old friends in new places
- Some new information
- With new material, about 17 more pages – still need to add this year's approved Agenda Items
- Cross-Walk is available
- Revised article numbers for other AASHTO LRFD specs have been provided

Thank You

Failure Modes - Tension



Failure Modes - Shear



What to Expect

- Some new/modified figures