
NCBC
National Concrete Bridge Council
2026 NCBC WEBINAR SERIES
Anchoring to Concrete- Updates for 2026: Part 3- Post-Installed Deformed Reinforcing Bars/Dowels
October 21, 2026
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NCBC Webinar Series 2026
November 18: Silica Fume: A Lever to Lowering Global Warming Potential and Increasing Service Life for Sustainable Infrastructure
Dates for 2027 TBD
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Industry Events 2026
Oct 29: Webinar- Overview of ANSI/PCI 142-24 Specification for Precast Prestressed Concrete Piles at 2:00 pm CT
Nov 8-11: ASBI Convention, San Antonio, TX
Nov 15-18: CRSI Fall Meeting, Chicago, IL
Dec 1-2: World Bridge Engineering Conference, Miami, FL
Jan 18–21, 2027: World of Concrete, Las Vegas
February 3–5, 2027: The Precast Show, Salt Lake City
March 7–10, 2027: NRMCA Convention, Louisville, KY
April 1-2, 2027: NCBC Extending Spans Workshop, Orlando, FL
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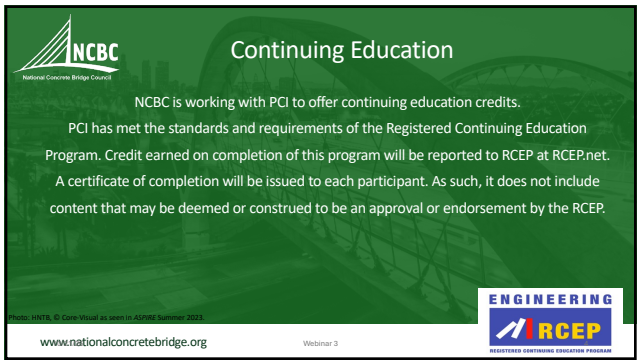
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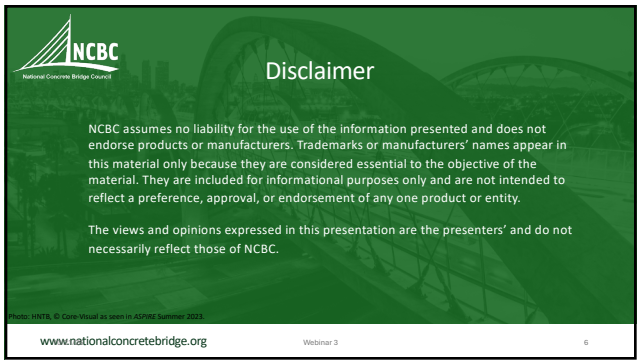
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Free ACI Anchor Resources

ACI has assembled an extensive collection of over 1000 pages that include full documents as well as anchor –related chapters and excerpts.
A few examples:
ACI 318-25 : Building Code for Structural Concrete (chapters 2, 17, 25, 26)
ACI 355.4: Post-Installed Adhesive Anchors in Concrete (complete document)
MNL-17 (21): ACI Reinforced Concrete Design Handbook (anchor design examples)

If you did not request access during the May or July webinar – you can request complimentary access to this collection of resources that address anchorage to concrete - please click the question icon during the webinar and type "ACI Docs"

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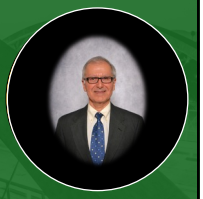
Bahram Sharooz , PhD, PE



- Professor Emeritus of structural engineering at the University of Cincinnati
- Principal investigator of research projects and design articles that led to the introduction of high-strength reinforcement, changes to strand debonding requirements, addition of 0.7-in. strands.
- Active in PCI Committee on Bridges and AASHTO Technical Committee for Concrete Design.

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Presentation

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Post-Installed Deformed Reinforcing Bars/Dowels

Bahram M. Shahrooz, PhD, PE, FACI, FASCE

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Acknowledgments

NCBC for sponsoring webinar series on anchorage to concrete

Financial support

- American Concrete Institute (ACI)
- Concrete Reinforcing Steel Institute (CRSI)
- Precast/Prestressed Concrete Institute (PCI)

Review and comments

- Neal Anderson – Simpson, Gumpertz & Heger
- Ronald Cook – Professor Emeritus, U. of Florida
- Donald Meinheit – Wiss, Janney, Elstner Associates

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Webinar Series

- Webinar 1: Screw anchors ✓
- Webinar 2: Attachments with shear lugs ✓

Changes in AASHTO 10th ed.

- Webinar 3: Post-installed reinforcing bars
  - Future editions of AASHTO
  - Some relevant discussions from emulated cast-in-place bridge systems (Accelerated Bridge Construction)

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Learning Objectives

- Discuss key differences between (a) post-installed adhesive anchors and (b) post-installed reinforcing bars
- Review important aspects of qualification requirements according to ACI CODE-355.5: *Post-Installed Reinforcing Bar Systems in Concrete-Qualification Requirements and Commentary*
- Go over general design and installation concepts
- Present examples of state DOT prequalified cementitious grouts for cast-in-place emulated bridge systems

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Side Note

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Clarification and Expansion of Adhesive Anchors

ACI 318-25, CH 17 has clarified and expanded what could be used as post-installed adhesive anchors

R17.1.2: "… steel elements for adhesive anchors may include threaded rods, **deformed reinforcing bars**, or internally threaded steel sleeves with external deformations."

Other changes in ACI 318-25 are summarized in extra slides.

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Examples of Internally Threaded Sleeves With External Deformations



Source: https://www.proventure.co.uk/products/chemical-anchors/internally-threaded-sleeve/



Source: https://www.hilti.com/c/CLS_FASTENER_7135/CLS_ANCHOR_RODS_ELEMENTS_7135/r260



Insert for coil rods

Source: https://www.contechshp.ie/wp-content/uploads/2024/01/1-1-anchoring_systems.pdf

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Post-Installed Deformed Reinforcing Bars

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Examples of Post-Installed Reinforcing Bars



Source: Bertrand, J., et al., Post-installed Rebar Anchoring Using Cementitious Grouts: An Alternative to Adhesive Anchoring presented at International Concrete Repair Institute, Fall Convention, 11/14/2013

Source: https://viewer.joomag.com/product-technical-guides-us-en-post-installed-rebar-guide-january-2023/0604970001570657600?short&

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ACI Qualification Requirements "ASTM-like" Testing Standards/Specification

- **ACI CODE-355.2**: Post-installed mechanical anchors
- **ACI CODE-355.4**: Post-installed adhesive anchors
- **ACI CODE-355.5**: Post-installed deformed reinforcing bars

  Qualified systems can be designed based on reinforcing bar provisions of ACI CODE-318, such as development length or splicing requirements.
  - #3 to #14 bars
  - Concrete

    f_c': 2,500 to 4,000 psi and 6,500 to 8,500 psi

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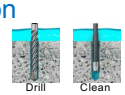
ACI CODE-355.5: Post-Installed Reinforcing Bar Systems in Concrete – Qualification

- Drilling and cleaning procedure
  - Similar to post-installed adhesive anchors
- "Standard" methods
  - A rotary hammer drill with a carbide bit (default method)
  - Core drilling
  - Rock drilling
- Products have to be qualified for the type of drilling method
  - Hole smoothness or roughness affects bond strength
- Holes are dry unless product was tested for water-filled holes or submerged concrete
  - Field condition must match product evaluation document



Source: https://www.youtube.com/watch?v=IL9sCyw_Ocw

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ACI CODE-355.5: Post-Installed Reinforcing Bar Systems in Concrete – Qualification

- Bonding of post-installed reinforcing bars to concrete is critical.
- Two bonding materials are specified in ACI CODE-355.5
  - Type A (adhesive grout)
  - Type B (cementitious grout)

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A Partial List of Qualification Tests – Type B Grouts

Only tension tests

Source: ACI CODE-355.5

Table 3.4—Test program for qualifying Type B grouts

Testing				Bar size	Assessment		f'_c[1]	Bar embedment ℓ_d	Minimum sample size n_{min}
Test no.	Test ref.	Purpose	Test parameters	U.S./ISO	α_{seq}	Load and displacement			
Reference tests									
1a	Ch. 6	Reference in low-strength concrete	Tension, confined, single bar[4]	No. 4 No. 8 $d_{b,max}$	—	12.3.2 12.4	Low	$7d_b$	Five per concrete batch
1b	Ch. 6	Reference in high-strength concrete[5]	Tension, confined, single bar[4]	$d_{b,max}$	—	12.3.2 12.4	High	$7d_b$	Five per concrete batch
1c	Ch. 6	Reference test at maximum long-term temperature	Tension, confined, single bar[4]	No. 4	—	12.3.2 12.4	Low	$7d_b$	Five per concrete batch
1d	Ch. 6	Reference test for freezing/thawing conditions	Tension, confined, single bar[4]	No. 4	—	12.3.2 12.4	High	$7d_b$	Five per concrete batch
Reliability tests									
2a	7.5	Sensitivity to hole cleaning, dry concrete	Tension, confined, single bar[4]	$d_{b,min}$	0.8	12.4.4	Low	$7d_b$	Five
2b	7.7	Sensitivity to hole cleaning, installation in a water-filled hole[6]	Tension, confined, single bar[4]	$d_{b,min}$	0.8	12.4.4	Low	$7d_b$	Five
2c	7.8	Sensitivity to hole cleaning, installation in submerged concrete[6]	Tension, confined, single bar[4]	$d_{b,min}$	0.8	12.4.4	Low	$7d_b$	Five
2d	7.9	Sensitivity to mixing effort	Tension, confined, single bar[4]	$d_{b,min}$	0.8	12.4.4	Low	$7d_b$	Five
3	7.10	Sensitivity to sustained load at elevated temperature	Tension, confined, single bar[4]	No. 4	0.9	12.4.4 12.5	Low	$7d_b$	Five
4	7.11	Sensitivity to installation direction	Tension, confined, single bar[4]	$d_{b,max}$	0.9	12.4.4 12.6	Low	$7d_b$	Five

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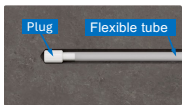
ACI CODE-355.5: Post-Installed Reinforcing Bar Systems in Concrete – Qualification

- Bonding materials could be pourable or injectable
- Installation direction is vertically down unless qualified for horizontal, vertically up, upwardly inclined
  - Piston and plug grouting systems for horizontal and upwardly inclined installations



Source (edited): https://www.youtube.com/watch?v=IL9sCyw_Qcw

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Bonding Materials
Adhesive vs. Cementitious

- Adhesives
  - Prepackaged
  - Manufacturer controlled (i.e., mixing nozzles)
- Cementitious grouts
  - Prepackaged or not
  - Installer controls water addition/mixing
  - More variability



Source: https://www.strongtie.com/miscadhesiveaccessories_adhesiveanchoringaccessories/ppdssystem_productgroup_as/p/piston-plug-delivery-system



Source: https://www.youtube.com/watch?v=yGLgWAU1Iz8

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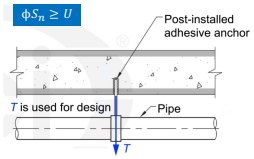
Differences Between Post-Installed Adhesive Anchors and Reinforcing Bars

- Post-installed adhesive anchors

$\phi S_n \geq U$



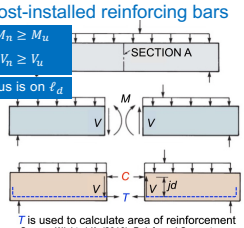
Source: ACI MNL-17 (modified)

- Post-installed reinforcing bars

$\phi M_n \geq M_u$

$\phi V_n \geq V_u$

Focus is on ℓ_d



Source: Wight, J.K. (2016), Reinforced Concrete Mechanics and Design (modified)

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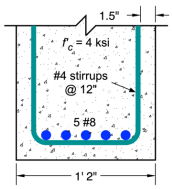
Differences Between Post-Installed Adhesive Anchors and Reinforcing Bars

- Embedment length of post-installed adhesive anchors is limited to $20d_a$ (d_a = anchor diameter)
  - Limited by testing
- Deformed reinforcing bar development length could be several times longer than $20d_b$ (d_b = reinforcing bar diameter) limit according to ACI Section 17.3.3



From AASHTO Eq.

$\ell_d \approx 61 d_b$

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Post-Installed Reinforcing Bars – Drilling

- When installing bars, special measures and equipment may be necessary to
  - Ensure hole straightness
  - Ensure plumbness/levelness
  - Prevent concrete damage
  - Avoid existing reinforcing bars
  - Avoid other embedded components

Deeper holes are harder to drill straight (drill bit wander)



Source: https://www.williamsform.com/concrete/spin-lock-concrete-anchors/spin-lock-concrete-anchors-installation/

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Post-Installed Reinforcing Bars – Drilling

- Use of jigs/fixtures can eliminate/minimize misalignment
  - Small misalignment in deep-drilled holes would reduce the amount of cover for post-installed reinforcing bars
- ACI CODE-355.5
  - Tolerance in drilling angle: 6 degrees to allow use of a hand-held hammer drill



without alignment aid



with alignment aid

Source: https://viewer.joomag.com/product-technical-guides-us-en-post-installed-rebar-guide-january-2024/0049700015710657600?short&

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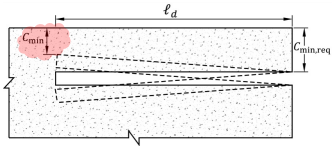
Concrete Cover: Post-Installed Reinforcing Bars (Guideline)



Hammer-drilled holes:

$$C_{\min,\text{req}} = 1.2 + 0.06\ell_d \geq 2d_b$$

Compressed-air (rock) drilled holes:

$$C_{\min,\text{req}} = 2.0 + 0.08\ell_d \geq 2d_b$$

Drill stand (e.g., core-drilled holes):

$$C_{\min,\text{req}} = 1.2 + 0.02\ell_d \geq 2d_b$$

Adapted from https://viewer.joomag.com/product-technical-guides-us-en-post-installed-rebar-guide-january-2024/0049700015710657600?short&

Note: Typically, carbide-tipped drill bits are at most around 30 in. long. A rock-drill or a core-drill is typically needed for deeper holes.

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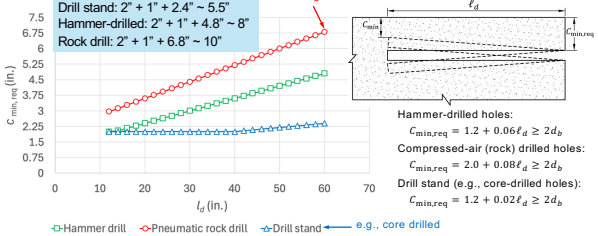
Concrete Cover: Post-Installed Reinforcing Bars (Guideline)

Drill stand: 2" + 1" + 2.4" ~ 5.5"
Hammer-drilled: 2" + 1" + 4.8" ~ 8"
Rock drill: 2" + 1" + 6.8" ~ 10"

a challenge for shallow members



Hammer-drilled holes:
$c_{min,req} = 1.2 + 0.06\ell_d \geq 2d_b$
Compressed-air (rock) drilled holes:
$c_{min,req} = 2.0 + 0.08\ell_d \geq 2d_b$
Drill stand (e.g., core-drilled holes):
$c_{min,req} = 1.2 + 0.02\ell_d \geq 2d_b$

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Cementitious Grout Examples

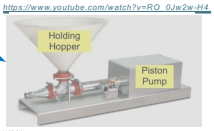
- HILTI HIT-FP 700 R injectable cementitious adhesive anchor
- SikaGrout-110 AN pourable grout (prepackaged, add water)
- Euclid Chemical Hi-Flow Grout
- MAPEI Planigrout 712
- Master Builders MasterFlow 928
- Sika SikaGrout 212

Texas DOT Prequalified Grouts

Source: Material Producer List, Materials and Tests Division, Texas Department of Transportation



Source: https://www.youtube.com/watch?v=RO_0Jw2w-H4



Source: https://www.kpmindustries.com/KingConstructionProducts/wp-content/uploads/sites/13/2014/08/CG-550-Series-Equipment-Sheet-ENG.pdf

Can post-installed bars be developed when these grouts are used? 🤔

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Cementitious Grout Examples
AMBEX AAC Anchoring Capsules


(a) (b) (c)


(d) (e)

- Used in several projects in Quebec
- Approved in Colorado, Maine, New York

Source: Bertrand, J., et al., Post-installed Rebar Anchoring Using Cementitious Grouts: An Alternative to Adhesive Anchoring presented at International Concrete Repair Institute, Fall Convention, 11/14/2013

Does it meet ACI CODE-355.5?
Can post-installed bars be developed with this grout? 🤔

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Bonding Materials
Flowable Cementitious Grouts for ABC Projects

Example of Accelerated Bridge Construction

Precast pier cap is connected to precast columns through grouted duct connections

Lake Belton, Texas Project



Source:
https://www.fhwa.dot.gov/bridge/prefab/if09010/report.pdf

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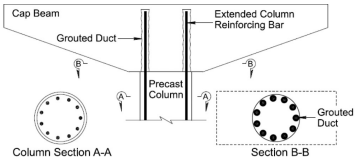
Grouted Duct Connections



Source: Caltrans Bridge Design Memo 20.34 (August 2025)



Courtesy of Dr. Bijan Khaleghi

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Bonding Materials
Flowable Cementitious Grouts for ABC Projects

Example from the Lake Belton, Texas ABC project

- Prepackaged, cementitious, non-shrink grout meeting ASTM C-1107 with additional requirements:
  - (a) compressive strength (b) expansion requirements, (c) modulus of elasticity, (d) coefficient of thermal expansion, (e) flowability, (f) set time, and (g) freeze-thaw cycles

See course resource document

- Other requirements:
  - No metallic formulations
  - Free of chlorides
  - No additives to be added to prepackaged grout
  - No frothing/foaming of fluid grout

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Bonding Materials
Flowable Cementitious Grouts for ABC Projects

Grout not tested according to ACI CODE 355.5 but has performed well

Grouted duct provides a significant level of confinement

AASHTO development length of straight bars:

$$\ell_d = 0.17 d_b \left(\frac{\lambda_{er} f_y - \frac{F_b}{A_b}}{1.97 \lambda_f' c^{0.25}} \right)^2 \times \lambda_{rl} \times \lambda_{cf} \times \lambda_{rc}$$

Reinforcement confinement factor

$0.3 \le \lambda_{rc} \le 1.0$

Gr. 60 bars developed into corrugated steel ducts:

$$\ell_d = \frac{0.67 d_{bl} f_{ye}}{\sqrt{f_g'}}$$

Ref.: *LRFD Guide Specifications for ABC*

$d_{bl} \equiv d_b$

Expected yield strength $f_{ye} = 68$ ksi

$f_g' \equiv f_c'$ $\quad f_{ye} \equiv f_y$ $\quad \lambda_{rl} = 1$ $\quad \lambda_{cf} = 1$ $\quad \lambda_{er} = 1$ $\quad \lambda = 1$

$\lambda_{rc} = 0.225$ to match the two development lengths

$\lambda_{rc} = 0.225 < 0.3 \Rightarrow$ confinement from steel ducts is better than the best confinement possible from standard transverse reinforcement

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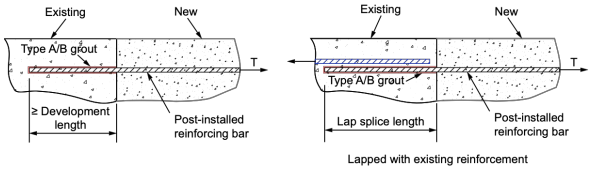
Post-Installed Deformed Reinforcing Bars
New or Spliced

Post-installed deformed reinforcing bars could be new reinforcement or spliced to existing reinforcement.



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Post-Installed Reinforcement
Design Methodology

- Flexural reinforcement quantity is determined based on standard reinforced concrete theories.
- Shear transfer between existing and new concrete is achieved by shear friction reinforcement.
- Flexural and shear friction reinforcement must be developed.
- Qualified post-installed deformed reinforcing bars per ACI CODE-355.5 are equivalent to cast-in bars of equal diameter and embedment for development length.

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ACI and AASHTO Development Length Equations

- ACI CODE-355.5 qualification is geared toward developing bars according to ACI requirements.
- Would meeting ℓ_d from ACI 318 also satisfy AASHTO LRFD?

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ACI and AASHTO Development Length Equations – Straight Bars

ACI 318-25 (25.4.2.4)

$$\ell_d = \left(\frac{3}{40}\frac{f_y}{\lambda\sqrt{f'_c}}\frac{\psi_t\psi_e\psi_s\psi_g}{\left(\frac{c_b + K_{tr}}{d_b}\right)}\right)d_b$$

$$\frac{c_b + K_{tr}}{d_b} \le 2.5$$

$$K_{tr} = \frac{40A_{tr}}{sn}$$

AASHTO LRFD (5.10.8.2.1)

$$\ell_d = 0.17 d_b \left(\frac{\lambda_{er} f_y - \frac{F_b}{A_b}}{1.97\lambda f_c'^{0.25}}\right)^2 \times \lambda_{ri} \times \lambda_{cf} \times \lambda_{rc}$$

$$\lambda_{rc} = \frac{d_b c_b}{(c_b(1-\beta_t) + 1.67 n_s k_{tr})^2}$$

$$0.30 \le \lambda_{rc} \le 1.0$$

$$k_{tr} = \frac{A_{tr}}{sn}$$

$$n_s = \frac{E_s}{E_c}$$

F_b = Force developed by a standard hook

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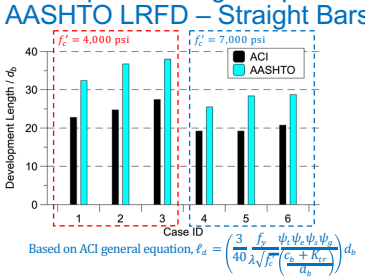
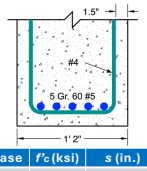
Development Length Equations from ACI vs. AASHTO LRFD – Straight Bars





Case	f'_c (ksi)	s (in.)
1	4	6
2	4	12
3	4	No stirrup
4	7	6
5	7	12
6	7	No stirrup

Based on ACI general equation, $\ell_d = \left(\frac{3}{40}\frac{f_y}{\lambda\sqrt{f'_c}}\frac{\psi_t\psi_e\psi_s\psi_g}{\left(\frac{c_b + K_{tr}}{d_b}\right)}\right)d_b$

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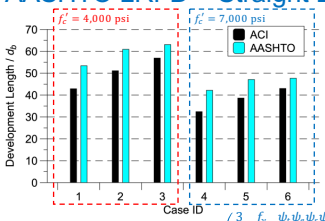
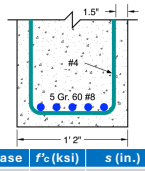
Development Length Equations from ACI vs. AASHTO LRFD – Straight Bars



Based on ACI general equation, $\ell_d = \left(\frac{3}{40}\frac{f_y}{\lambda\sqrt{f'_c}}\frac{\psi_t\psi_e\psi_s\psi_g}{\left(\frac{c_b + K_{tr}}{d_b}\right)}\right)d_b$



Case	f'_c (ksi)	s (in.)
1	4	6
2	4	12
3	4	No stirrup
4	7	6
5	7	12
6	7	No stirrup

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Bridge Deck Widening – Example

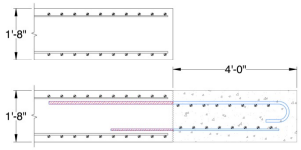
Design parameters

A 20-inch-thick deck in a 3-span slab bridge is to be widened by 8 ft (4 ft on each side)

f'_{ceq} = 5,000 psi (equivalent compressive strength from core samples)

M_u = 48 k-ft/ft

V_u = 12 k/ft



Design objective

Determine the amount of Grade 60 reinforcement in the extension and required embedment lengths

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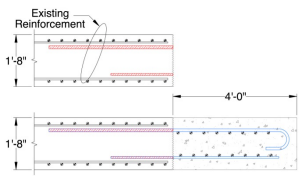
Bridge Deck Widening – Example

Steps

- Calculate required reinforcement in the extension
- Locate existing reinforcement (verified by GPR scan, as needed)
- Roughen the exposed faces
- Drill and install new reinforcement per Manufacturer's Printed Installation Instructions (MPII)
- Install formwork and cast new concrete after curing time specified in MPII



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Bridge Deck Widening – Example

Design parameters

A 20-inch-thick deck in a 3-span slab bridge is to be widened by 8 ft (4 ft on each side)

$f_c' = f_{ceq}' = 5{,}000$ psi (equivalent cylinder strength from core samples)

Grade 60 reinforcement

$M_u = 48$ k-ft/ft

$V_u = 12$ k/ft

Steps

Calculate flexural reinforcement to resist 48 k-ft/ft and shear friction reinforcement to resist 12 k/ft

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Bridge Deck Widening – Example

Flexural reinforcement: #8 @ 12 in. on the top

To accommodate the existing bars, the flexural reinforcement must be placed with a 4.5" cover

$d = 20'' - (4.5'' + 1''/2) = 15''$

$$\phi M_n = \phi A_s f_y \left(d - \frac{A_s f_y}{2\times 0.85 f_c' b}\right) = 0.9\times 0.79\times 60\times \left(15 - \frac{0.79\times 60}{2\times 0.85\times 5\times 12}\right)$$

ϕM_n = 620 k-in./ft = 51.7 k-ft/ft > M_u (48 k-ft/ft) → OK

Required development length:

ACI 318-25: 33.1 in. say 34 in.

AASHTO LRFD: 27.5 in.

See extra slides

Class B splice: 34 in. x 1.3 = 44.2 in. say 48 in.

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Bridge Deck Widening – Example

To "decouple" shear and moment, flexural reinforcement is not used as shear friction reinforcement. Try shear friction reinforcement: #5 @ 12 in. in the bottom

ACI 318-25

$\phi V_n = \phi(\mu A_{vf}) f_y = \phi(1.0\lambda A_{vf}) f_y$ (surface intentionally roughened)

$\phi V_n = 0.75(1.0\times 1\times 0.31 \text{ in.}^2/\text{ft}) 60{,}000 \text{ psi}$ = 13,950 lb/ft = 13.9 k/ft > V_u (12 k/ft) → OK

AASHTO LRFD

$\phi V_n = \phi\left(cA_{vf} + \mu(A_{vf} + P_c)\right) \rightarrow \phi(\mu A_{vf}) f_y$ if cohesion is ignored and because $P_c = 0$.

$\phi V_n = 0.90(1.0\times 1\times 0.31 \text{ in.}^2/\text{ft}) 60 \text{ ksi}$ = 16.7 k/ft > V_u (12 k/ft) → OK

Shear reinforcement needs to develop its yield strength to be effective as shear friction reinforcement. Development length = 12.7" from ACI and 17.2" from AASHTO. Use the longer value from AASHTO.

Class B splice: 17.2 in. x 1.3 = 22.4 in. say 24 in.

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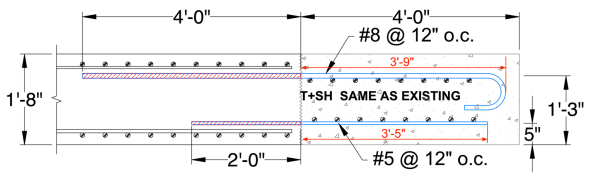
Bridge Deck Widening – Example



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Summary

- I discussed the main differences between post-installed reinforcing bars and post-installed adhesive anchors.
  - Embedment length
  - Installation
  - Design methodology
- Standard methods for design of reinforced concrete elements can be applied to post-installed reinforcing bars.

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Summary

- Key component is bonding materials
  - Adhesive grout (Type A qualified according to ACI CODE-355.5)
  - Cementitious grout (Type B qualified according to ACI CODE-355.5)
- Adhesive grouts are more widely available than cementitious grouts
- Several state DOTs have a list of prequalified flowable cementitious grouts
  - Unclear if these meet ACI CODE-355.5 qualification requirements

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Summary

- For grouted connections with corrugated steel tubes, development length is much smaller than "standard" ℓ_d.
  - Confinement from steel tube
  - Post-installed deformed reinforcing bars do not have the confinement from steel tube ⟶ much longer development length
- Emulated cast-in-place bridge systems have performed well.
  - Grouts were not qualified as Type B according to ACI CODE-355.5
  - Such grouts could potentially be justified for applications involving post-installed reinforcing bars in bridges.

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Thank you.

You now are familiar with the basic concepts for design of post-installed reinforcing bars and are aware of potential challenges with finding bonding materials qualified according to ACI CODE 355.5.

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Webinar Documents

https://www.pci.org/AnchoringToConcreteImp

8 2026 Anchoring Imp Series Webinar 3 with Dr. Shahrooz October 21 2026

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Questions
Key Takeaways



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NCBC
National Concrete Bridge Council

Thank you!

Please sign up for future NCBC webinars

www.nationalconcretebridge.org

Photo: HNTB, © Core-Visual as seen in *ASPIRE* Summer 2023.

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Extra Slides

Summary of Ch. 17 changes in ACI 318-25 in addition to permitting the use of post-installed deformed reinforcing bars

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ACI 318-25 Ch. 17 Other Changes

- "Repackaging" of strength reduction factors and introduction of redundant and non-redundant anchors
- A new factor $\psi_{cm,N}$ to account for beneficial effects of overturning moment on breakout in tension for anchors in compression
- Revision of tension-shear interaction equation
- Anchor reinforcement instead of tensile and shear concrete breakout strength
  - A new equation for calculation of tensile breakout strength of bar groups used as anchor reinforcement
  - Clarifications on use and placement of reinforcement

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Revised Safety Factors in ACI 318-25

Tensile concrete failure modes: concrete breakout, side-face blowout, bond

Supplementary Reinforcement	ACI 318-19			ACI 318-25						
	Anchor Type	Anchor Category*	ϕ	Anchor Type	Anchor Category*	ψ_a	Redundant ϕ	Redundant $\phi\psi_a$	Non-redundant ϕ	Non-redundant $\phi\psi_a$
Present	Cast-in-place	N/A	0.75	Cast-in-place	N/A	1.00	0.75	0.75	0.65	0.65
	Post-installed	1	0.75	Post-installed	1	1.00	0.75	0.75		0.65
		2	0.65		2	0.85	0.64	0.64		0.55
		3	0.55		3	0.75	0.56	0.56		0.49
Not present	Cast-in-place	N/A	0.70	Cast-in-place	N/A	0.95	0.71	0.71		0.62
	Post-installed	1	0.65	Post-installed	1	0.85	0.64	0.64		0.55
		2	0.55		2	0.75	0.56	0.56		0.49
		3	0.45		3	0.60	0.45	0.45		0.39

* From ACI 355.2 or 355.4

Per ACI: "Redundancy may be assumed where it can be shown that failure of a single anchor or anchorage point does not result in loss of position retention or progressive collapse."

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Revised Safety Factors in ACI 318-25

Tensile failure mode: pullout

ACI 318-19			ACI 318-25						
Anchor Type	Anchor Category*	ϕ	Anchor Type	Anchor Category*	ψ_a	Redundant ϕ	Redundant $\phi\psi_a$	Non-redundant ϕ	Non-redundant $\phi\psi_a$
Cast-in-place	N/A	0.70	Cast-in-place	N/A	0.95	0.75	0.71	0.65	0.62
Post-installed	1	0.65	Post-installed	1	0.85		0.64		0.55
	2	0.55		2	0.75		0.56		0.49
	3	0.45		3	0.60		0.45		0.39

* From ACI 355.2 or 355.4

Per ACI: "Redundancy may be assumed where it can be shown that failure of a single anchor or anchorage point does not result in loss of position retention or progressive collapse."

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Revised Safety Factors in ACI 318-25

Shear concrete failure mode: concrete breakout

Supplementary Reinforcement	ACI 318-19			ACI 318-25				
	Anchor Type	Anchor Category*	ϕ	Anchor Type	Anchor Category*	ψ_a	ϕ	$\phi\psi_a$
Present	Cast-in-place	N/A	0.75	Cast-in-place	N/A	1.00	0.75	0.75
	Post-installed	1		Post-installed	1			
		2			2			
		3			3			
Not present	Cast-in-place	N/A	0.70	Cast-in-place	N/A	0.95		0.71
	Post-installed	1		Post-installed	1			
		2			2			
		3			3			

* From ACI 355.2 or 355.4

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Revised Safety Factors in ACI 318-25

Shear failure mode: concrete pryout

ACI 318-19			ACI 318-25				
Anchor Type	Anchor Category*	ϕ	Anchor Type	Anchor Category*	ψ_a	ϕ	$\phi\psi_a$
Cast-in-place	N/A	0.70	Cast-in-place	N/A	0.95	0.75	0.71
Post-installed	1		Post-installed	1			
	2			2			
	3			3			

* From ACI 355.2 or 355.4

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Tension-Shear Interaction Equation

Single anchor concrete strength

$$\left(\frac{N_{ua}}{\phi N_{n,c}}\right)^{\frac{5}{3}} + \left(\frac{V_{ua}}{\phi V_{n,c}}\right)^{\frac{5}{3}} \leq 1$$

Anchor group concrete strength

$$\left(\frac{N_{ua,g}}{\phi N_{n,cg}}\right)^{\frac{5}{3}} + \left(\frac{V_{ua,g}}{\phi V_{n,cg}}\right)^{\frac{5}{3}} \leq 1$$

Single or group anchor steel strength

$$\left(\frac{N_{ua}}{\phi N_{sa}}\right)^{2} + \left(\frac{V_{ua}}{\phi V_{sa}}\right)^{2} \leq 1$$

Note: Interaction is checked regardless of the values of the ratio of factored tensile force to tensile strength and the ratio of factored shear force to shear strength

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Anchor Reinforcement Clarification

- If factored tensile or shear force is larger than the concrete breakout strength or if the breakout strength is not checked, strength of anchor reinforcement can be used.
- Placement of anchor reinforcement for tension and shear are provided in the next two slides.

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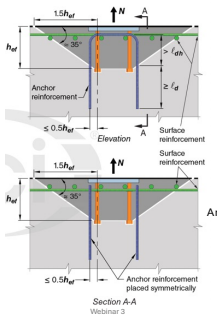

Anchor reinforcement for tension

Source: ACI 318-25 Figure R17.5.2.1a

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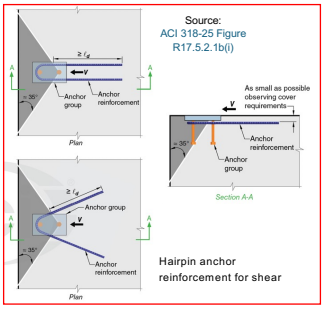
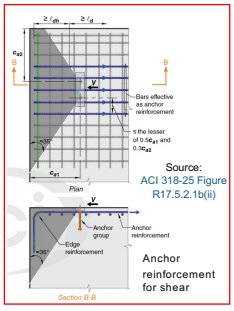


Source: ACI 318-25 Figure R17.5.2.1b(i)

Hairpin anchor reinforcement for shear



Source: ACI 318-25 Figure R17.5.2.1b(ii)

Anchor reinforcement for shear

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Reinforcement Bar Groups For Anchorage Reinforcement

- Multiple, closely spaced bars can fail in breakout
  - Occurs even if the reinforcement meets development length requirements.
- Must evaluate the breakout strength of the member in which the bars are terminated.
- Tensile breakout strength of bar groups
  - $\phi N_{rg} = \phi\left(N_{cbg} + N_{srg}\right)\ \ \phi = 0.75$
  - N_{cbg} = Nominal concrete breakout strength in tension of a group of anchors
  - N_{srg} = Contribution of parallel reinforcement to the nominal breakout strength of a reinforcing bar group

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Concrete Breakout Strength of Anchor Groups

An anchor group (ACI Eq. 17.6.2.1b):

$\phi N_{cbg} = 0.75(A_{Nc}/A_{Nco})\psi_a\psi_{ec,N}\ \psi_{ed,N}\ \psi_{c,N}\ \psi_{cp,N}\ \psi_{cm,N}N_b$

N_b = Basic concrete breakout strength in tension of a single anchor in cracked concrete (lb)

$N_b = k_c\lambda_a\sqrt{f'_c}{h_{ef}}^{1.5}$

k_c = 17 for post-installed anchors (may be increased based on ACI CODE-355.2 or ACI CODE-355.4 product tests but not to exceed 24)

λ_a = Lightweight concrete modification factor

$\lambda_a = 0.8\lambda$ for screw anchors (also for expansion and adhesive anchor concrete failure)

λ = modification factor for lightweight concrete (Note: This factor is different in ACI (section 19.2.4) and AASHTO (Article 5.4.2.8)

f'_c = Concrete compressive strength in psi

h_{ef} = Effective anchor embedment depth

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N_{cbg} - Modifications

Nominal concrete breakout strength in tension of a group of anchors is calculated similar to what was discussed in Webinar 1.

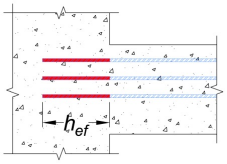
The following modifications are applied:

h_{ef} = effective embedment depth of reinforcing bars measured from the end of the bar to the critical section (where the bar has to develop its yielding strength)

$N_b = k_c\lambda_a\sqrt{f'_c}{h_{ef}}^{1.5}$

k_c = 35 for straight reinforcing bars (it is 40 for hooked and deformed bars)

$\psi_{c,N} = 1$



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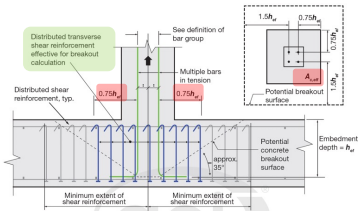
$$N_{srg} = \rho_t A_{c,eff} f_y$$

$A_{c,eff}$ = Concrete area containing reinforcement parallel to reinforcing bar group and enclosed within a distance of $0.75h_{ef}$ from the perimeter of the reinforcing bar group

f_y = Yield strength of reinforcement

ρ_t = Ratio of area of distributed transverse reinforcement to gross concrete area perpendicular to that reinforcement



Source:
ACI 318-25 Figure R25.4.11.5a

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Distributed Reinforcement Requirements

Distributed reinforcement effective for N_{srg} must meet the following requirements:

(a) Reinforcement must be parallel to the bar group and located within $A_{c,eff}$

(b) If $N_{rg} \leq 2.5N_{cbg}$, reinforcement must be spaced at $0.5h_{ef}$ or less in each orthogonal direction

(c) If $N_{rg} > 2.5N_{cbg}$, reinforcement must be spaced at $0.25h_{ef}$ or less in each orthogonal direction

(d) Reinforcement must extend over at least 90% of the embedment depth of the bar group and be terminated beyond the end of the bar group

(e) Reinforcement must have a head or a hook at each end, and must meet detailing requirements for stirrups

(f) Reinforcing bar diameter must not exceed the diameter of the smallest bar in the bar group

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Calculation of Development Length For Bridge Widening Example

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Development Length Equation – ACI Tension (#8) – Top Bars

$$\ell_d = \left(\frac{3}{40}\frac{f_y}{\lambda\sqrt{f'_c}}\frac{\psi_t\psi_e\psi_s\psi_g}{\left(\frac{c_b + K_{tr}}{d_b}\right)}\right)d_b \qquad \frac{c_b + K_{tr}}{d_b} \le 2.5 \qquad K_{tr} = \frac{40A_{tr}}{sn}$$

No transverse reinforcement will be provided, so $K_{tr} = 0$

Distance to the center of bars = 5"

Center-to-center spacing of bars = 12"

c_b = smaller of (5" and 12"/2) = 5"

$\frac{c_b + K_{tr}}{d_b} = \frac{5 + 0}{1} = 5 \quad \rightarrow \quad \frac{c_b + K_{tr}}{d_b} = 2.5$

$\psi_t = 1.3$ because there will be more than 12" of fresh concrete below the bars

$\lambda = \psi_e = \psi_s = \psi_g = 1$

$f'_c = 5{,}000$ psi $\quad f_y = 60{,}000$ psi $\quad d_b = 1"$

$\ell_d = 33.1" \approx 34"$

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Development Length Equation – AASHTO Tension (#8) – Top Bars

$$\ell_d = 0.17 d_b \left(\frac{\lambda_{er} f_y - \frac{F_b}{A_b}}{1.97\lambda f_c'^{0.25}}\right)^2 \times\lambda_{rl}\times\lambda_{cf}\times\lambda_{rc} \qquad \lambda_{rc} = \frac{d_b c_b}{(c_b(1-\beta_t) + 1.67 n_s k_{tr})^2} \qquad 0.30 \le \lambda_{rc} \le 1.0$$

$k_{tr} = \frac{A_{tr}}{sn}$ $\qquad n_s = \frac{E_s}{E_c}$ $\qquad F_b$ = Force developed by a standard hook

No transverse reinforcement will be provided, so $k_{tr} = 0$

$c_b = 5"$ (the same as ACI equation) $\qquad F_b = 0$ (straight bar)

$\beta_t = 0$ (there is no permanent compressive force)

$n_s = \frac{E_s}{E_c} = \frac{E_s}{2{,}500 f_c'^{0.33}} = \frac{29{,}000}{2{,}500\times 5^{0.33}} = 6.82 \qquad \lambda_{rc} = \frac{1\times 5}{(5(1-0) + 1.67\times 6.82\times 0)^2} = 0.2 \rightarrow \lambda_{rc} = 0.3$

$\lambda_{rl} = 1.3$ because there will be more than 12" of fresh concrete below the bars

$\lambda = \lambda_{er} = \lambda_{cf} = 1$

$f'_c = 5$ ksi $\qquad f_y = 60$ ksi $\qquad d_b = 1"$

$\ell_d = 27.5"$

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Development Length Equation – ACI Tension (#5) – Bottom Bars

$$\ell_d = \left(\frac{3}{40}\frac{f_y}{\lambda\sqrt{f'_c}}\frac{\psi_t\psi_e\psi_s\psi_g}{\left(\frac{c_b + K_{tr}}{d_b}\right)}\right)d_b \qquad \frac{c_b + K_{tr}}{d_b} \le 2.5 \qquad K_{tr} = \frac{40A_{tr}}{sn}$$

No transverse reinforcement will be provided, so $K_{tr} = 0$

Distance to the center of bars = 5"

Center-to-center spacing of bars = 12"

c_b = smaller of (5" and 12"/2) = 5"

$\frac{c_b + K_{tr}}{d_b} = \frac{5 + 0}{1} = 5 \quad \rightarrow \quad \frac{c_b + K_{tr}}{d_b} = 2.5$

$\lambda = \psi_e = \psi_g = \psi_t = 1 \qquad \psi_s = 0.8$

$f'_c = 5{,}000$ psi $\quad f_y = 60{,}000$ psi $\quad d_b = 5/8"$

$\ell_d = 12.7"$

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Development Length Equation – AASHTO Tension (#5) – Bottom Bars

$$\ell_d = 0.17 d_b \left(\frac{\lambda_{er} f_y - \frac{F_b}{A_b}}{1.97 \lambda_f \sqrt{f'_c}} \right)^2 \times \lambda_{rl} \times \lambda_{cf} \times \lambda_{rc} \qquad \lambda_{rc} = \frac{d_b c_b}{(c_b(1-\beta_t) + 1.67 n_s k_{tr})^2} \quad 0.30 \le \lambda_{rc} \le 1.0$$

$k_{tr} = \frac{A_{tr}}{sn}$ $\qquad n_s = \frac{E_s}{E_c}$ $\qquad F_b$ = Force developed by a standard hook

No transverse reinforcement will be provided, so $k_{tr} = 0$

$c_b = 5$" (the same as ACI equation) $\qquad F_b = 0$ (straight bar)

$\beta_t = 0$ (there is no permanent compressive force)

$n_s = \frac{E_s}{E_c} = \frac{E_s}{2{,}500 f_c'^{0.33}} = \frac{29{,}000}{2{,}500 \times 5^{0.33}} = 6.82$ $\qquad \lambda_{rc} = \frac{1 \times 5}{(5(1-0) + 1.67 \times 6.82 \times 0)^2} = 0.2 \rightarrow \lambda_{rc} = 0.3$

$\lambda = \lambda_{er} = \lambda_{cf} = \lambda_{rl} = 1$

$f'_c = 5$ ksi $\qquad f_y = 60$ ksi $\qquad d_b = 5/8$"

$\ell_d = 17.2$"