



CONNECT AND PROTECT

Headed Bar and Mechanical Anchor Design Aid

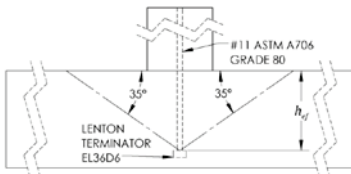

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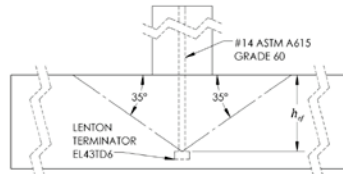
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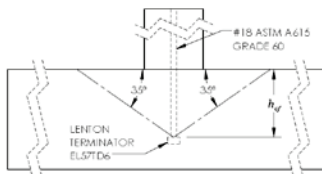
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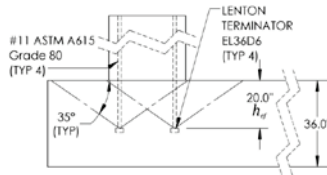
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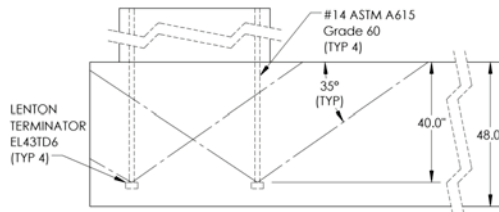
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INTRODUCTION

The nVent LENTON Headed Bar and Mechanical Anchor Design Aid is provided to facilitate designing reinforcing bar anchorage with the nVent LENTON Terminator and nVent LENTON Ultimate headed bar anchor systems.

Since the issuing of ACI 318-08, relevant sections of ACI 318 have been utilized to provide guidance on designing with headed deformed bars to ensure that the effective embedment in concrete is sufficient to develop the necessary force in the reinforcing bar, refer to Section 25.4.4 of ACI 318-14 (12.6 of ACI 318-11). However, when criteria in Section 25.4.4.1 of ACI 318-14 (12.6.1 of ACI 318-11) is not met, a widespread unfamiliarity exists regarding acceptable methods for performing design calculations. This design aid provides various example calculations for headed reinforcing bar following Chapter 17 of ACI 318-14 (Appendix D of ACI 318-11). In each design example, the following failure modes are evaluated:

1. Concrete breakout strength in tension (N_{cb}), Section 17.4.2 of ACI 318-14 (D.5.2 of ACI 318-11).
2. Pullout strength in tension (N_{pn}), Section 17.4.3 of ACI 318-14 (D.5.3 of ACI 318-11).
3. Concrete side-face blowout strength in tension (N_{sb}), Section 17.4.4 of ACI 318-14 (D.5.4 of ACI 318-11).

The nVent LENTON Headed Bar and Mechanical Anchor Design Aid examples are intended to be used for reference only. The Engineer of Record shall ensure that calculations and designs are performed properly for the corresponding applications and requirements.

EXAMPLE A1: Replacing a standard hook with a single anchor of #11 Grade 60 or Grade 80 rebar

The initial design for a connection between two cast-in-place concrete members calls for a standard hook with #11 ASTM A615 Grade 60 rebar in normalweight concrete with a compressive strength (f'_c) of 4,000 psi. According to Section 25.4.3 of ACI 318-14 (12.5 of ACI 318-11), the minimum development length of the hook is 26.8 inches. Due to the need to develop the required strength in a shorter length, the hook is then replaced with a mechanical anchor. As all conditions of Section 25.4.4.1 of ACI 318-14 (12.6.1 of ACI 318-11) are met, the development length is calculated by the following equation from Section 25.4.4.2 of ACI 318-14 (12.6.2 of ACI 318-11):

$$l_{dt} = \left(\frac{0.016 f_y \psi_e}{\sqrt{f'_c}} \right) d_b$$

Symbol	Value	Unit	ACI 318 -14	ACI 318 -11	Description
f_y	60,000	psi	-	-	Specified yield strength of the reinforcing bar.
ψ_e	1.0	-	25.4.4.3	12.6.2	Modification factor for development length, based on coating, 1.0 for black bar, 1.2 for epoxy coated.
f'_c	4,000	psi	-	-	Specified compressive strength of concrete.
d_b	1.41	in	-	-	Nominal diameter of reinforcing bar.

$$l_{dt} = \left(\frac{0.016 \left(60,000 \frac{\text{lb}}{\text{in}^2} \right) (1.0)}{\sqrt{4,000 \left(\frac{\text{lb}}{\text{in}^2} \right)}} \right) (1.41 \text{ in})$$

$$l_{dt} = 21.4 \text{ in}$$

For this particular scenario, the development length is determined to be 21.4 inches, which is approximately 80% of the required development length for a hooked bar under equal circumstances. For reference, the tables below contain development length charts for hooked and headed bars according to the calculation methods from the referenced sections of ACI 318.

Development Lengths (l_{dh}) for Hooked Bars per Section 25.4.3 of ACI 318-14 (12.5 of ACI 318-11), inch					
Bar Size		Concrete Compressive Strength, psi			
ASTM	mm	3,000	4,000	5,000	6,000
#4	12	11.0	9.5	8.5	7.7
#5	16	15.3	13.3	10.6	9.7
#6	20	16.4	14.2	12.7	11.6
#7	22	19.2	16.6	14.8	13.6
#8	25	21.9	19.0	17.0	15.5
#9	28	24.7	21.4	19.1	17.5
#10	32	27.8	24.1	21.6	19.7
#11	36	30.9	26.8	23.9	21.8

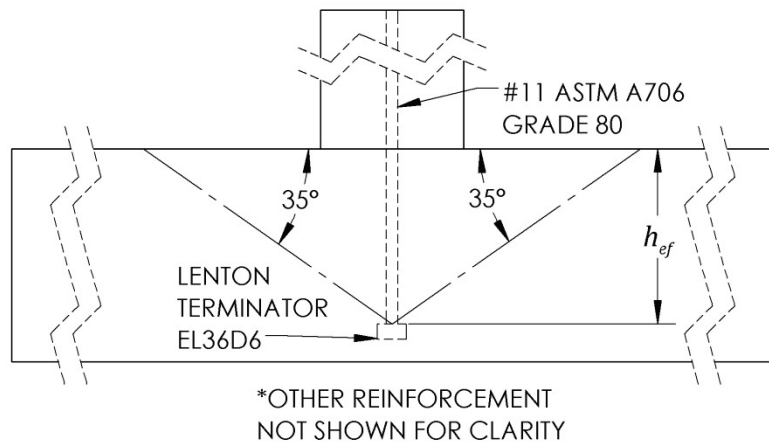
Calculations based on 60 ksi (yield) black bar, normalweight concrete, and cover and reinforcement reduction factors set to 1.0.

Development Lengths (l_{dt}) for Headed Bars per Section 25.4.4 of ACI 318-14 (12.6 of ACI 318-11), inch					
Bar Size		Concrete Compressive Strength, psi			
ASTM	mm	3,000	4,000	5,000	6,000
#4	12	8.8	7.6	6.8	6.2
#5	16	11.0	9.5	8.5	7.7
#6	20	13.1	11.4	10.2	9.3
#7	22	15.3	13.3	11.9	10.8
#8	25	17.5	15.2	13.6	12.4
#9	28	19.8	17.1	15.3	14.0
#10	32	22.3	19.3	17.2	15.7
#11	36	24.7	21.4	19.1	17.5

Calculations based on 60 ksi (yield) black bar and normalweight concrete, assuming that all conditions in 25.4.4.1 (ACI 318-14) are met.

The design is then modified to use ASTM A706 Grade 80 rebar, rather than ASTM A615 Grade 60. As the use of Grade 80 rebar does not comply to condition (b) of Section 25.4.4.1 of ACI 318-14 (12.6.1 of ACI 318-11), Chapter 17 of ACI 318-14 (Appendix D of ACI 318-11) may be used to perform the necessary design calculations on the headed reinforcing bar, treating it as an anchor.

Evaluating the headed rebar to Chapter 17 of ACI 318-14 (Appendix D of ACI 318-11) enables the calculation of concrete breakout strength in tension (N_{cb}), pullout strength in tension (N_{pn}), and concrete side-face blowout strength in tension (N_{sb}) to ensure that the designed performance meets the factored tensile force (N_{ua}), which in this example is 124,800 lbf (80,000 psi x 1.56 in²).



Concrete Breakout Strength in Tension (N_{cb}) and Effective Embedment Depth (h_{ef}):

Breakout strength in tension can be calculated with the provided equations in Section 17.4.2 of ACI 318-14 (D.5.2 of ACI 318-11). However, for design purposes, the variable for effective embedment depth (h_{ef}) is solved for from the relevant equations. As shown in the equation below, h_{ef} is the required embedment to provide adequate breakout strength for the selected factored design strength. See *Appendix B, Solving for h_{ef}* in this design aid for the derivation of the equation shown below.

$$h_{ef} = \left[\frac{N_{ua}}{\phi \frac{A_{Nc}}{A_{Nco}} \psi_{ed,N} \psi_{c,N} \psi_{cp,N} k_c \lambda_a \sqrt{f'_c}} \right]^{2/3}$$

Symbol	Value	Unit	ACI 318 -14	ACI 318 -11	Description
N_{ua}	124,800	lbf	-	-	Factored tensile force applied to an anchor.
ϕ	0.70	-	17.3.3(c)	D.4.3(c)	Strength reduction factor for anchors governed by concrete breakout, when supplementary reinforcement is not present (Condition B).
A_{Nc}/A_{Nco}	1.0	-	R17.4.2.1	RD.5.2.1	Actual projected failure area (A_{Nc}) divided by theoretical projected failure area (A_{Nco}), set equal to 1.0 for a single anchor away from edges.
$\psi_{ed,N}$	1.0	-	17.4.2.5	D.5.2.5	Modification factor for edge proximity, when not affected by edge, set equal to 1.0.
$\psi_{c,N}$	1.25	-	17.4.2.6	D.5.2.6	Modification factor based on presence or absence of cracks, 1.25 for no cracks.
$\psi_{cp,N}$	1.0	-	17.4.2.7	D.5.2.7	Modification factor for post-installed anchors, set equal to 1.0 for cast-in anchors.
k_c	24	-	17.4.2.2	D.5.2.2	Coefficient for basic concrete breakout strength in tension.
λ_a	1.0	-	17.2.6	D.3.6	Modification factor for lightweight concrete, normalweight = 1.0.
f'_c	4,000	psi	-	-	Specified compressive strength of concrete.

$$h_{ef} = \left[\frac{124,800 \text{ lbf}}{(0.70)(1.0)(1.0)(1.25)(1.0)(24)(1.0)\sqrt{4,000 \text{ psi}}} \right]^{2/3}$$

$$h_{ef} = 20.7 \text{ in}$$

Alternate Equation for Concrete Breakout Strength (N_{cb}) and Effective Embedment Depth (h_{ef}):

If the effective embedment depth (h_{ef}) is greater than or equal to 11 inches and less than or equal to 25 inches, the equation previously used in this example (whose root equation is found in Section 17.4.2.2a of ACI 318-14 (equation D-6 of ACI 318-11)) can be too conservative in certain cases, see comments in Section R17.4.2.2 of ACI 318-14 (RD.5.2.2 of ACI 318-11). For this reason, the alternate equation is provided in 17.4.2.2b of ACI 318-14 (Equation D-7 of ACI 318-11). The alternate effective embedment depth (h_{ef}) is then calculated with the equation below (refer to Appendix B in this design aid for its derivation), where all variables remain the same as shown in the prior calculation, except that the value for k_c of 24 is replaced with 16, per Section 17.4.2.2b of ACI 318-14 (D-7 of ACI 318-11).

$$h_{ef} = \left[\frac{N_{ua}}{\phi \frac{A_{Nc}}{A_{Nco}} \psi_{ed,N} \psi_{c,N} \psi_{cp,N} k_c 16 \lambda_a \sqrt{f'_c}} \right]^{3/5}$$

$$h_{ef} = \left[\frac{124,800 \text{ lbf}}{(0.70)(1.0)(1.0)(1.25)(1.0)(16)(1.0)\sqrt{4,000 \text{ psi}}} \right]^{3/5}$$

$$h_{ef} = 19.5 \text{ in}$$

Note that even with a higher strength rebar (f_y of 80,000 psi), the calculations based on Chapter 17 of ACI 318-14 (12.6 of ACI 318-11) result in shorter effective embedment depths (20.7 inches and 19.5 inches) compared to the development length of 21.4 inches calculated according to Section 25.4.4.2 of ACI 318-14 (12.6.2 of ACI 318-11) with rebar at 60,000 psi f_y . Under certain conditions, such as single anchors located away from edges, calculating the effective embedment depth to Chapter 17 of ACI 318-14 (Appendix D of ACI 318-11) may result in shorter effective embedment depths. However, it must be understood that changes to the variables (f_y , N_{ua} , f'_c , spacing, clear cover, etc.) will have varying impacts on the calculated results. Using Chapter 17 of ACI 318-14 (Appendix D of ACI 318-11) may result in a shorter effective embedment depth under a particular set of conditions, but not under a separate set of conditions. Therefore, evaluating to both calculation methods (when applicable), can be a wise practice for design optimization.

Pullout Strength of Cast-in Anchor in Tension (N_{pn}): The nominal pullout strength of a single cast-in anchor (N_{pn}) can be calculated from the equations found in Section 17.4.3 of ACI 318-14 (D.5.3 of ACI 318-11) by substituting for N_p (pullout strength of a single anchor in cracked concrete), as shown below. Note that N_{pn} is representative of the load at which initial crushing of the concrete occurs, not the load required to pull the anchor out of the concrete entirely, reference Section R17.4.3.4 of ACI 318-14 (RD.5.3.4 of ACI 318-11).

$$N_{pn} = \psi_{c,P} N_p \quad N_p = 8A_{brg} f'_c$$

$$N_{pn} = \psi_{c,P} 8A_{brg} f'_c$$

Symbol	Value	Unit	ACI 318 -14	ACI 318 -11	Description
$\psi_{c,P}$	1.4	in ²	17.4.3.6	D.5.3.6	Modification factor based on presence or absence of cracks, set equal to 1.4 for no cracks, 1.0 for cracking at service load levels.
A_{brg}	6.74	in ²	-	-	Net bearing area of EL36D6 Terminator.
f'_c	4,000	psi	-	-	Specified compressive strength of concrete.

$$N_{pn} = (1.4)(8)(6.74 \text{ in}^2)(4,000 \text{ psi})$$

$$N_{pn} = 301,952 \text{ lbf}$$

Even when the strength reduction factor (ϕ) of 0.70 is multiplied by N_{pn} , the result is still well above the factored tensile load applied to the anchor (N_{ua}), which, in this example is 124,800 lbf. Reference Sections 17.3.3 of ACI 318-14 (D.4.3 of ACI 318-11) and 17.3.1.1 of ACI 318-14 (D4.1.1 of ACI 318-11).

$$\phi N_{pn} \geq N_{ua}$$

$$(0.70)(301,952 \text{ lbf}) \geq 124,800 \text{ lbf}$$

$$211,366 \text{ lbf} \geq 124,800 \text{ lbf}$$

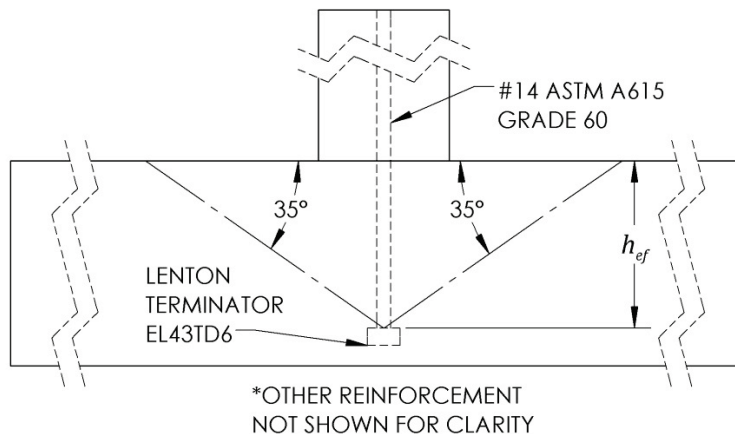
Side-Face Blowout Strength of a Headed Anchor in Tension (N_{sb}): For anchors with the effective embedment depth (h_{ef}) greater than $2.5(c_{a1})$, where c_{a1} is the distance from the center of the anchor to the nearest edge, the side-face blowout strength of a headed anchor in tension can be determined from Section 17.4.4 of ACI 318-14 (D.5.4 of ACI 318-11). As $2.5(c_{a1})$ is greater than h_{ef} in this example, N_{sb} need not be considered.

Summary:

- h_{ef} for the ASTM A706 Grade 80 #11 rebar embedded in normalweight 4,000 psi concrete is calculated to be 19.5 in, based on a factored design strength (N_{ua}) of 124,800 lbf.
- $\phi N_{pn} \geq N_{ua}$ (211,366 lbf \geq 124,800 lbf).
- Evaluation of the side-face blowout strength (N_{sb}) is not required.

EXAMPLE A2: Single anchor with #14 Grade 60 rebar

An engineer has designed for a single nVent LENTON Terminator EL43TD6 positioned away from all edges to be used with uncoated #14 ASTM A615 Grade 60 rebar in normalweight concrete with a compressive strength (f'_c) of 4,000 psi. As the use of #14 rebar does not comply to condition (c) of Section 25.4.4.2 of ACI 318-14 (12.6.1 of ACI 318-11), Chapter 17 of ACI 318-14 (Appendix D of ACI 318-11) may be utilized for design purposes. *Note that Section 17.3.2.2 of ACI 318-14 (D.4.2.2 of ACI 318-11) permits use of anchor diameters up to 4 inches.*



Evaluating the headed rebar to Chapter 17 of ACI 318-14 (Appendix D of ACI 318-11) enables the calculation of concrete breakout strength in tension (N_{cb}), pullout strength in tension (N_{pn}), and concrete side-face blowout strength in tension (N_{sb}) to ensure that the designed performance meets the factored tensile force (N_{ua}), which in this case is 135,000 lbf.

Concrete Breakout Strength in Tension (N_{cb}) and Effective Embedment Depth (h_{ef}):

Breakout strength in tension can be calculated with the provided equations in Section 17.4.2 of ACI 318-14 (D.5.2 of ACI 318-11). However, for design purposes, the variable for effective embedment depth (h_{ef}) is solved for from the relevant equations. See *Appendix B, Solving for h_{ef}* in this design aid for the derivation of the equation shown below.

$$h_{ef} = \left[\frac{N_{ua}}{\phi \frac{A_{Nc}}{A_{Nco}} \psi_{ed,N} \psi_{c,N} \psi_{cp,N} k_c \lambda_a \sqrt{f'_c}} \right]^{2/3}$$

Symbol	Value	Unit	ACI 318 -14	ACI 318 -11	Description
N_{ua}	135,000	lbf	-	-	Factored tensile force applied to an anchor.
ϕ	0.70	-	17.3.3(c)	D.4.3(c)	Strength reduction factor for anchors governed by concrete breakout, when supplementary reinforcement is not present (Condition B).
A_{Nc}/A_{Nco}	1.0	-	R17.4.2.1	RD.5.2.1	Actual projected failure area (A_{Nc}) divided by theoretical projected failure area (A_{Nco}), set equal to 1.0 for a single anchor away from edges.
$\psi_{ed,N}$	1.0	-	17.4.2.5	D.5.2.5	Modification factor for edge proximity, when not affected by edge, set equal to 1.0.
$\psi_{c,N}$	1.25	-	17.4.2.6	D.5.2.6	Modification factor based on presence or absence of cracks, 1.25 for no cracks.
$\psi_{cp,N}$	1.0	-	17.4.2.7	D.5.2.7	Modification factor for post-installed anchors, set equal to 1.0 for cast-in anchors.
k_c	24	-	17.4.2.2	D.5.2.2	Coefficient for basic concrete breakout strength in tension.
λ_a	1.0	-	17.2.6	D.3.6	Modification factor for lightweight concrete, normalweight = 1.0.
f'_c	4,000	psi	-	-	Specified compressive strength of concrete.

$$h_{ef} = \left[\frac{135,000 \text{ lbf}}{(0.70)(1.0)(1.0)(1.25)(1.0)(24)(1.0)\sqrt{4,000 \text{ psi}}} \right]^{2/3}$$

$$h_{ef} = 21.8 \text{ in}$$

Alternate Equation for Concrete Breakout Strength (N_{cb}) and Effective Embedment Depth (h_{ef}):

If the effective embedment depth (h_{ef}) is greater than or equal to 11 inches and less than or equal to 25 inches, the equation previously used in this example, (whose root equation is found in Section 17.4.2.2a of ACI 318-14 (equation D-6 of ACI 318-11)) can be too conservative in certain cases, see comments in Section R17.4.2.2 of ACI 318-14 (RD.5.2.2 of ACI 318-11). For this reason, the alternate equation is provided in 17.4.2.2b of ACI 318-14 (Equation D-7 of ACI 318-11). The alternate effective embedment depth (h_{ef}) is then calculated with the equation below (refer to Appendix B in this design aid for its derivation), where all variables remain the same as shown in the prior calculation, except that the value for k_c of 24 is replaced with 16, per Section 17.4.2.2b of ACI 318-14 (D-7 of ACI 318-11).

$$h_{ef} = \left[\frac{N_{ua}}{\phi \frac{A_{Nc}}{A_{Nco}} \psi_{ed,N} \psi_{c,N} \psi_{cp,N} k_c 16 \lambda_a \sqrt{f'_c}} \right]^{3/5}$$

$$h_{ef} = \left[\frac{135,000 \text{ lbf}}{(0.70)(1.0)(1.0)(1.25)(1.0)(16)(1.0)\sqrt{4,000 \text{ psi}}} \right]^{3/5}$$

$$h_{ef} = 20.4 \text{ in}$$

Pullout Strength of Cast-in Anchor in Tension (N_{pn}): The nominal pullout strength of a single cast-in anchor (N_{pn}) can be calculated from the equations found in Section 17.4.3 of ACI 318-14 (D.5.3 of ACI 318-11) by substituting for N_p (pullout strength of a single anchor in cracked concrete), as shown below. Note that N_{pn} is representative of the load at which initial crushing of the concrete occurs, not the load required to pull the anchor out of the concrete entirely, reference Section R17.4.3.4 of ACI 318-14 (RD.5.3.4 of ACI 318-11).

$$N_{pn} = \psi_{c,P} N_p \quad N_p = 8A_{brg} f'_c$$

$$N_{pn} = \psi_{c,P} 8A_{brg} f'_c$$

Symbol	Value	Unit	ACI 318 -14	ACI 318 -11	Description
$\psi_{c,P}$	1.4	in ²	17.4.3.6	D.5.3.6	Modification factor based on presence or absence of cracks, set equal to 1.4 for no cracks, 1.0 for cracking at service load levels.
A_{brg}	10.316	in ²	-	-	Net bearing area of EL43TD6 Terminator.
f'_c	4,000	psi	-	-	Specified compressive strength of concrete.

$$N_{pn} = (1.4)(8)(10.316 \text{ in}^2)(4,000 \text{ psi})$$

$$N_{pn} = 462,157 \text{ lbf}$$

Even when the strength reduction factor (ϕ) of 0.70 is multiplied by N_{pn} , the result is still well above the factored tensile load applied to the anchor (N_{ua}). Reference Sections 17.3.3 of ACI 318-14 (D.4.3 of ACI 318-11) and 17.3.1.1 of ACI 318-14 (D4.1.1 of ACI 318-11).

$$\phi N_{pn} \geq N_{ua}$$

$$(0.70)(462,157 \text{ lbf}) \geq 135,000 \text{ lbf}$$

$$323,510 \text{ lbf} \geq 135,000 \text{ lbf}$$

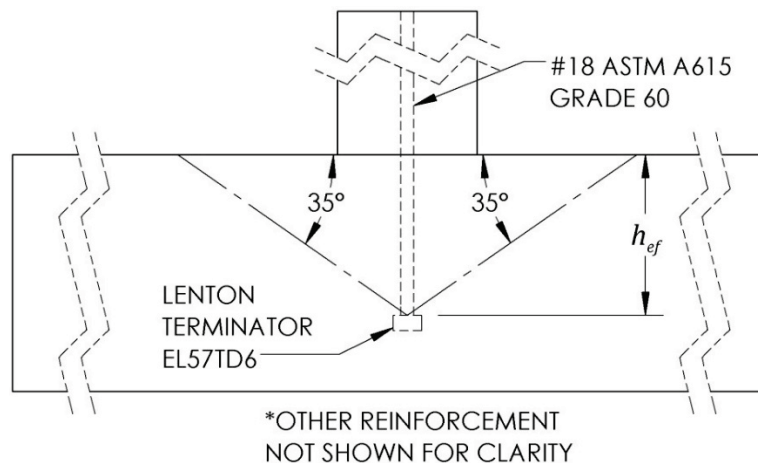
Side-Face Blowout Strength of a Headed Anchor in Tension (N_{sb}): For anchors with an effective embedment depth (h_{ef}) greater than $2.5(c_{a1})$, where c_{a1} is the distance from the center of the anchor to the nearest edge, the side-face blowout strength of a headed anchor in tension can be determined from Section 17.4.4 of ACI 318-14 (D.5.4 of ACI 318-11). As $2.5(c_{a1})$ is greater than h_{ef} in this example, N_{sb} need not be considered.

Summary:

- h_{ef} for the ASTM A615 Grade 60 #14 rebar embedded in normalweight 4,000 psi concrete is calculated to be 20.4 in, based on a factored design strength (N_{ua}) of 135,000 lbf.
- $\phi N_{pn} \geq N_{ua}$ (323,510 lbf \geq 135,000 lbf).
- Evaluation of the side-face blowout strength (N_{sb}) is not required.

EXAMPLE A3: Single anchor with #18 Grade 60 rebar

An engineer has designed for a single nVent LENTON Terminator EL57TD6 positioned away from all edges to be used with uncoated #18 ASTM A615 Grade 60 rebar in normalweight concrete with a compressive strength (f'_c) of 4,000 psi. As the use of #18 rebar does not comply to condition (c) of Section 25.4.4.2 of ACI 318-14 (12.6.1 of ACI 318-11), Chapter 17 of ACI 318-14 (Appendix D of ACI 318-11) may be utilized for design purposes. *Note that Section 17.3.2.2 of ACI 318-14 (D.4.2.2 of ACI 318-11) permits use of anchor diameters up to 4 inches.*



Evaluating the headed rebar to Chapter 17 of ACI 318-14 (Appendix D of ACI 318-11) enables the calculation of concrete breakout strength in tension (N_{cb}), pullout strength in tension (N_{pn}), and concrete side-face blowout strength in tension (N_{sb}) to ensure that the designed performance meets the factored tensile force (N_{ua}), which in this case is 240,000 lbf.

Concrete Breakout Strength in Tension (N_{cb}) and Effective Embedment Depth (h_{ef}):

Breakout strength in tension can be calculated with the provided equations in Section 17.4.2 of ACI 318-14 (D.5.2 of ACI 318-11). However, for design purposes, the variable for effective embedment depth (h_{ef}) is solved for from the relevant equations. See *Appendix B, Solving for h_{ef}* in this design aid for the derivation of the equation shown below.

$$h_{ef} = \left[\frac{N_{ua}}{\phi \frac{A_{Nc}}{A_{Nco}} \psi_{ed,N} \psi_{c,N} \psi_{cp,N} k_c \lambda_a \sqrt{f'_c}} \right]^{2/3}$$

Symbol	Value	Unit	ACI 318 -14	ACI 318 -11	Description
N_{ua}	240,000	lbf	-	-	Factored tensile force applied to an anchor.
ϕ	0.70	-	17.3.3(c)	D.4.3(c)	Strength reduction factor for anchors governed by concrete breakout, when supplementary reinforcement is not present (Condition B).
A_{Nc}/A_{Nco}	1.0	-	R17.4.2.1	RD.5.2.1	Actual projected failure area (A_{Nc}) divided by theoretical projected failure area (A_{Nco}), set equal to 1.0 for a single anchor away from edges.
$\psi_{ed,N}$	1.0	-	17.4.2.5	D.5.2.5	Modification factor for edge proximity, when not affected by edge, set equal to 1.0.
$\psi_{c,N}$	1.25	-	17.4.2.6	D.5.2.6	Modification factor based on presence or absence of cracks, 1.25 for no cracks.
$\psi_{cp,N}$	1.0	-	17.4.2.7	D.5.2.7	Modification factor for post-installed anchors, set equal to 1.0 for cast-in anchors.
k_c	24	-	17.4.2.2	D.5.2.2	Coefficient for basic concrete breakout strength in tension.
λ_a	1.0	-	17.2.6	D.3.6	Modification factor for lightweight concrete, normalweight = 1.0.
f'_c	4,000	psi	-	-	Specified compressive strength of concrete.

$$h_{ef} = \left[\frac{240,000 \text{ lbf}}{(0.70)(1.0)(1.0)(1.25)(1.0)(24)(1.0)\sqrt{4,000 \text{ psi}}} \right]^{2/3}$$

$$h_{ef} = 32.0 \text{ in}$$

Alternate Equation for Concrete Breakout Strength (N_{cb}) and Effective Embedment Depth (h_{ef}):

If the effective embedment depth (h_{ef}) is greater than or equal to 11 inches and less than or equal to 25 inches, the equation previously used in this example, (whose root equation is found in Section 17.4.2.2a of ACI 318-14 (equation D-6 of ACI 318-11)) can be too conservative in certain cases, see comments in Section R17.4.2.2 of ACI 318-14 (RD.5.2.2 of ACI 318-11). For this reason, the alternate equation is provided in 17.4.2.2b of ACI 318-14 (Equation D-7 of ACI 318-11). The alternate effective embedment depth (h_{ef}) is then calculated with the equation below (refer to Appendix B in this design aid for its derivation), where all variables remain the same as shown in the prior calculation, except that the value for k_c of 24 is replaced with 16, per Section 17.4.2.2b of ACI 318-14 (D-7 of ACI 318-11).

$$h_{ef} = \left[\frac{N_{ua}}{\phi \frac{A_{Nc}}{A_{Nco}} \psi_{ed,N} \psi_{c,N} \psi_{cp,N} k_c 16 \lambda_a \sqrt{f'_c}} \right]^{3/5}$$

$$h_{ef} = \left[\frac{240,000 \text{ lbf}}{(0.70)(1.0)(1.0)(1.25)(1.0)(16)(1.0)\sqrt{4,000 \text{ psi}}} \right]^{3/5}$$

$$h_{ef} = 28.8 \text{ in}$$

Pullout Strength of Cast-in Anchor in Tension (N_{pn}): The nominal pullout strength of a single cast-in anchor (N_{pn}) can be calculated from the equations found in Section 17.4.3 of ACI 318-14 (D.5.3 of ACI 318-11) by substituting for N_p (pullout strength of a single anchor in cracked concrete), as shown below. Note that N_{pn} is representative of the load at which initial crushing of the concrete occurs, not the load required to pull the anchor out of the concrete entirely, reference Section R17.4.3.4 of ACI 318-14 (RD.5.3.4 of ACI 318-11).

$$N_{pn} = \psi_{c,P} N_p \quad N_p = 8A_{brg} f'_c$$

$$N_{pn} = \psi_{c,P} 8A_{brg} f'_c$$

Symbol	Value	Unit	ACI 318 -14	ACI 318 -11	Description
$\psi_{c,P}$	1.4	in ²	17.4.3.6	D.5.3.6	Modification factor based on presence or absence of cracks, set equal to 1.4 for no cracks, 1.0 for cracking at service load levels.
A_{brg}	16.669	in ²	-	-	Net bearing area of EL57TD6 Terminator.
f'_c	4,000	psi	-	-	Specified compressive strength of concrete.

$$N_{pn} = (1.4)(8)(16.669 \text{ in}^2)(4,000 \text{ psi})$$

$$N_{pn} = 746,771 \text{ lbf}$$

Even when the strength reduction factor (ϕ) of 0.70 is multiplied by N_{pn} , the result is still well above the factored tensile load applied to the anchor (N_{ua}). Reference Sections 17.3.3 of ACI 318-14 (D.4.3 of ACI 318-11) and 17.3.1.1 of ACI 318-14 (D4.1.1 of ACI 318-11).

$$\phi N_{pn} \geq N_{ua}$$

$$(0.70)(746,771 \text{ lbf}) \geq 240,000 \text{ lbf}$$

$$522,740 \text{ lbf} \geq 240,000 \text{ lbf}$$

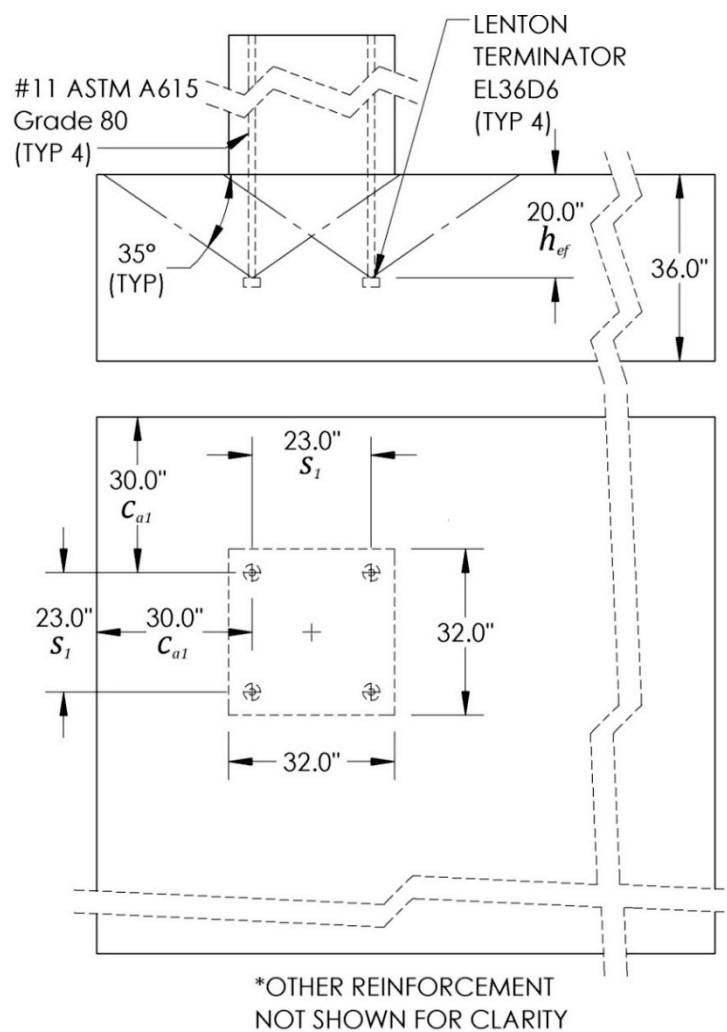
Side-Face Blowout Strength of a Headed Anchor in Tension (N_{sb}): For anchors with an effective embedment depth (h_{ef}) greater than $2.5(c_{a1})$, where c_{a1} is the distance from the center of the anchor to the nearest edge, the side-face blowout strength of a headed anchor in tension can be determined from Section 17.4.4 of ACI 318-14 (D.5.4 of ACI 318-11). As $2.5(c_{a1})$ is greater than h_{ef} in this example, N_{sb} need not be considered.

Summary:

- h_{ef} for the ASTM A615 Grade 60 #18 rebar embedded in normalweight 4,000 psi concrete is calculated to be 28.8 in, based on a factored design strength (N_{ua}) of 240,000 lbf.
- $\phi N_{pn} \geq N_{ua}$ (522,740 lbf \geq 240,000 lbf).
- Evaluation of the side-face blowout strength (N_{sb}) is not required.

Example B1, Group of anchors with #11 Grade 80 rebar

An engineer's design includes four nVent LENTON Terminator EL36D6 rebar anchors to be used with #11 ASTM A706 Grade 80 rebar to anchor a cast in place column to a mat foundation. The Terminators are configured as shown in the image below. These anchors meet the definition of an anchor group (defined as "a number of similar anchors having approximately equal effective embedment depths with spacing between adjacent anchors such that the projected areas overlap," reference Section 2.3 of ACI 318-14 (Section D.1 of ACI 318-11)). Evaluating the anchor group to Chapter 17 of ACI 318-14 (Appendix D of ACI 318-11) enables the calculation of concrete breakout strength in tension for a single anchor (N_{cb}) or a group of anchors (N_{cbg}), pullout strength in tension (N_{pn}), and concrete side-face blowout strength in tension for a single anchor (N_{sb}) or a group of anchors (N_{sbg}) to ensure that the calculated performance meets the design's factored tensile force of 249,600 lbf for the group of anchors ($N_{ua,g}$), and 62,400 lbf for a single anchor (N_{ua}).



Concrete Breakout Strength in Tension of a Single Anchor (N_{cb}): Breakout strength in tension can be calculated for a single anchor with the equation found in Section 17.4.2.1a of ACI 318-14 (D.5.2.1a of ACI 318-11).

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

As the effective embedment depth (h_{ef}) of the anchor is greater than or equal to 11 in and less than or equal to 25 in, N_b is calculated from equation 17.4.2.2b of ACI 318-14 (D-7 of ACI 318-11).

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

Symbol	Value	Unit	ACI 318 -14	ACI 318 -11	Description
λ_a	1.0	-	17.2.6	D.3.6	Modification factor for lightweight concrete, normalweight = 1.0.
f'_c	4,000	psi	-	-	Specified compressive strength of concrete.
h_{ef}	20.0	in	-	-	Effective embedment depth of anchor.

$$N_b = 16(1.0)\sqrt{4,000 \text{ psi}} (20 \text{ in})^{5/3}$$

$$N_b = 149,119 \text{ lbf}$$

With each of the variables and reduction factors known in equation 17.4.2.1a of ACI 318-14 (D-3 of ACI 318-11), N_{cb} can be solved for.

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

Symbol	Value	Unit	ACI 318 -14	ACI 318 -11	Description
A_{Nc}/A_{Nco}	1.0	-	R17.4.2.1	RD.5.2.1	Actual projected failure area (A_{Nc}) divided by theoretical projected failure area (A_{Nco}), set equal to 1.0 for a single anchor away from edges.
$\psi_{ed,N}$	1.0	-	17.4.2.5	D.5.2.5	Modification factor for edge proximity, when not affected by edge, set equal to 1.0.
$\psi_{c,N}$	1.25	-	17.4.2.6	D.5.2.6	Modification factor based on presence or absence of cracks, 1.25 for no cracks.
$\psi_{cp,N}$	1.0	-	17.4.2.7	D.5.2.7	Modification factor for post-installed anchors, set equal to 1.0 for cast-in anchors.
N_b	149,119	lbf	17.4.2.2	D.5.2.2	Basic concrete breakout strength in tension of single anchor.

$$N_{cb} = (1.0)(1.0)(1.25)(1.0)(149,119 \text{ lbf})$$

$$N_{cb} = 186,399 \text{ lbf}$$

According to Section 17.3.1.1 of ACI 318-14 (D.4.1.1 of ACI 318-11), the concrete breakout strength of a single anchor (N_{cbg}) multiplied by the strength reduction factor (ϕ) must be greater than or equal to the factored tensile force applied to the anchor (N_{ua}).

$$\phi N_{cb} \geq N_{ua}$$

Symbol	Value	Unit	ACI 318 -14	ACI 318 -11	Description
ϕ	0.70	-	17.3.3(c)	D.4.3(c)	Strength reduction factor for anchors governed by concrete breakout, when supplementary reinforcement is not present (Condition B).
N_{cb}	186,399	lbf	17.3.1.1 & 17.4.2.1	D.4.1.1 & D.5.2.1	Nominal concrete breakout strength in tension of a group of anchors.
N_{ua}	62,400	lbf	-	-	Factored tensile force applied to anchor or group of anchors.

$$(0.70)(186,399 \text{ lbf}) \geq 62,400 \text{ lbf}$$

$$130,479 \text{ lbf} \geq 62,400 \text{ lbf}$$

Concrete Breakout Strength in Tension of Group of Anchors (N_{cgb}): Breakout strength in tension can be calculated for a group of anchors with the equation found in Section 17.4.2.1b of ACI 318-14 (D.5.2.1b of ACI 318-11).

$$N_{cgb} = \frac{A_{Nc'}}{A_{Nco}} \psi_{ec,N} \psi_{ed,N} \psi_{c,N} \psi_{cp,N} N_b$$

To start, the variable of $A_{Nc'}$ ($A_{Nc'}$ is used in this design aid to represent a group of anchors, where A_{Nc} is used to represent a single anchor) must be determined according to Section 17.4.2.1 of ACI 318-14 (D.5.2.1 of ACI 318-11). In this scenario, the anchors are all located at least $1.5h_{ef}$ from any edge, therefore, $A_{Nc'}$ can be calculated as shown below (values for each variable can be found in the diagram at the beginning of this example):

$$A_{Nc'} = (c_{a1} + s_1 + 1.5h_{ef})^2$$

Symbol	Value	Unit	ACI 318 -14	ACI 318 -11	Description
c_{a1}	30	in	R17.4.2.1	RD.5.2.1	Minimum edge distance to center of anchor.
s_1	23	in	R17.4.2.1	RD.5.2.1	Center to center spacing of anchors.
h_{ef}	20	in	-	-	Effective embedment depth of anchor.

$$A_{Nc'} = (30 \text{ in} + 23 \text{ in} + 1.54(20))^2$$

$$A_{Nc'} = 6,889 \text{ in}^2$$

A_{Nco} is determined by the equation 17.4.2.1c of ACI 318-14 (D-5 of ACI 318-11).

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

$$A_{Nco} = 9(20 \text{ in})^2$$

$$A_{Nco} = 3,600 \text{ in}^2$$

With each of the variables and reduction factors known in equation 17.4.2.1b of ACI 318-14 (D-4 of ACI 318-11), N_{cbg} can be solved for.

$$N_{cbg} = \frac{A_{Nc'}}{A_{Nco}} \psi_{ec,N} \psi_{ed,N} \psi_{c,N} \psi_{cp,N} N_b$$

Symbol	Value	Unit	ACI 318 -14	ACI 318 -11	Description
A_{Nc}'	6,889	in ²	R17.4.2.1 & 17.4.2.3	RD.5.2.1 & D.5.2.3	Projected concrete failure area of a group of anchors.
A_{Nco}	3,600	in ²	17.4.2.1	D.5.2.1	Projected concrete failure area of a single anchor not limited by edge or spacing.
A_{Nc}'/A_{Nco}	1.914	-	R17.4.2.1	RD.5.2.1	Actual projected failure area of the group of anchors (A_{Nc}') divided by theoretical projected failure area (A_{Nco}).
$\psi_{ec,N}$	1.0	-	17.4.2.4	D.5.2.4	Modification factor for anchor groups loaded eccentrically in tension, set equal to 1.0 if load is centered in anchor group.
$\psi_{ed,N}$	1.0	-	17.4.2.5	D.5.2.5	Modification factor for edge proximity, when not affected by edge, set equal to 1.0.
$\psi_{c,N}$	1.25	-	17.4.2.6	D.5.2.6	Modification factor based on presence or absence of cracks, 1.25 for no cracks.
$\psi_{cp,N}$	1.0	-	17.4.2.7	D.5.2.7	Modification factor for post-installed anchors, set equal to 1.0 for cast-in anchors.
N_b	149,119	lbf	17.4.2.2	D.5.2.2	Basic concrete breakout strength in tension of single anchor.

$$N_{cbg} = (1.914)(1.0)(1.0)(1.25)(1.0)(149,119 \text{ lbf})$$

$$N_{cbg} = 356,767 \text{ lbf}$$

According to Section 17.3.1.1 of ACI 318-14 (D.4.1.1 of ACI 318-11), the concrete breakout strength of a group of anchors (N_{cbg}) multiplied by the strength reduction factor (ϕ) must be greater than or equal to the factored tensile force applied to the group of anchors ($N_{ua,g}$).

$$\phi N_{cbg} \geq N_{ua,g}$$

Symbol	Value	Unit	ACI 318 -14	ACI 318 -11	Description
ϕ	0.70	-	17.3.3(c)	D.4.3(c)	Strength reduction factor for anchors governed by concrete breakout, when supplementary reinforcement is not present (Condition B).
N_{cbg}	356,581	lbf	17.3.1.1 & 17.4.2.1	D.4.1.1 & D.5.2.1	Nominal concrete breakout strength in tension of a group of anchors.
$N_{ua,g}$	249,600	lbf	-	-	Factored tensile force applied to anchor or group of anchors.

$$(0.70)(356,767 \text{ lbf}) \geq 249,600 \text{ lbf}$$

$$249,737 \text{ lbf} \geq 249,600 \text{ lbf}$$

In cases where the nominal breakout strength does not meet the required load, the engineer may consider increasing variables such as: anchor spacing, distance from anchor to concrete edge, effective embedment depth, bearing area of the anchor (Section 17.4.2.8 of ACI 318-14 or D.5.2.8 of ACI 318-11), and/or concrete compressive strength. Other considerations may include the addition of supplemental reinforcement (Section 17.3.3 of ACI 318-14 or D.4.3 of ACI 318-11), the inclusion of anchor reinforcement, and/or altering the relationship between the effective embedment depth and d (ACI 318 defines d as the "distance from extreme compression fiber to centroid of longitudinal tension reinforcement, in."), such that the effective embedment depth is greater than $(1.5)(d)$ – precluding breakout failure, refer to Section 17.4.2.9 of ACI 318-14 or D.5.2.9 of ACI 318-11. Also see Appendix C of this design aid for additional information and useful references.

Pullout Strength of Cast-in Anchor in Tension (N_{pn}): The nominal pullout strength of a single cast-in anchor (N_{pn}) can be calculated from the equations found in Section 17.4.3 of ACI 318-14 (D.5.3 of ACI 318-11) by substituting for N_p (pullout strength of a single anchor in cracked concrete), as shown below. Note that N_{pn} is representative of the load at which initial crushing of the concrete occurs, not the load required to pull the anchor out of the concrete entirely, reference Section R17.4.3.4 of ACI 318-14 (RD.5.3.4 of ACI 318-11).

$$N_{pn} = \psi_{c,P} N_p \quad N_p = 8A_{brg} f'_c$$

$$N_{pn} = \psi_{c,P} 8A_{brg} f'_c$$

Symbol	Value	Unit	ACI 318-14	ACI 318-11	Description
$\psi_{c,P}$	1.4	in ²	17.4.3.6	D.5.3.6	Modification factor based on presence or absence of cracks, set equal to 1.4 for no cracks, 1.0 for cracking at service load levels.
A_{brg}	6.735	in ²	-	-	Net bearing area of EL36D6 Terminator.
f'_c	4,000	psi	-	-	Specified compressive strength of concrete.

$$N_{pn} = (1.4)(8)(6.735 \text{ in}^2)(4,000 \text{ psi})$$

$$N_{pn} = 301,728 \text{ lbf}$$

Even when the strength reduction factor (ϕ) of 0.70 is multiplied by N_{pn} , the result is still well above the factored tensile load applied to the anchor (N_{ua}). Reference Sections 17.3.3 of ACI 318-14 (D.4.3 of ACI 318-11) and 17.3.1.1 of ACI 318-14 (D4.1.1 of ACI 318-11).

$$\phi N_{pn} \geq N_{ua}$$

$$(0.70)(301,728 \text{ lbf}) \geq 62,400 \text{ lbf}$$

$$211,210 \text{ lbf} \geq 62,400 \text{ lbf}$$

Side-Face Blowout Strength of a Headed Anchor in Tension (N_{sb}): For anchors with an effective embedment depth (h_{ef}) greater than $2.5(c_{a1})$, where c_{a1} is the distance from the center of the anchor to the nearest edge, the side-face blowout strength of a headed anchor in tension can be determined from Section 17.4.4 of ACI 318-14 (D.5.4 of ACI 318-11). As $2.5(c_{a1})$ is greater than h_{ef} in this example, N_{sb} need not be considered.

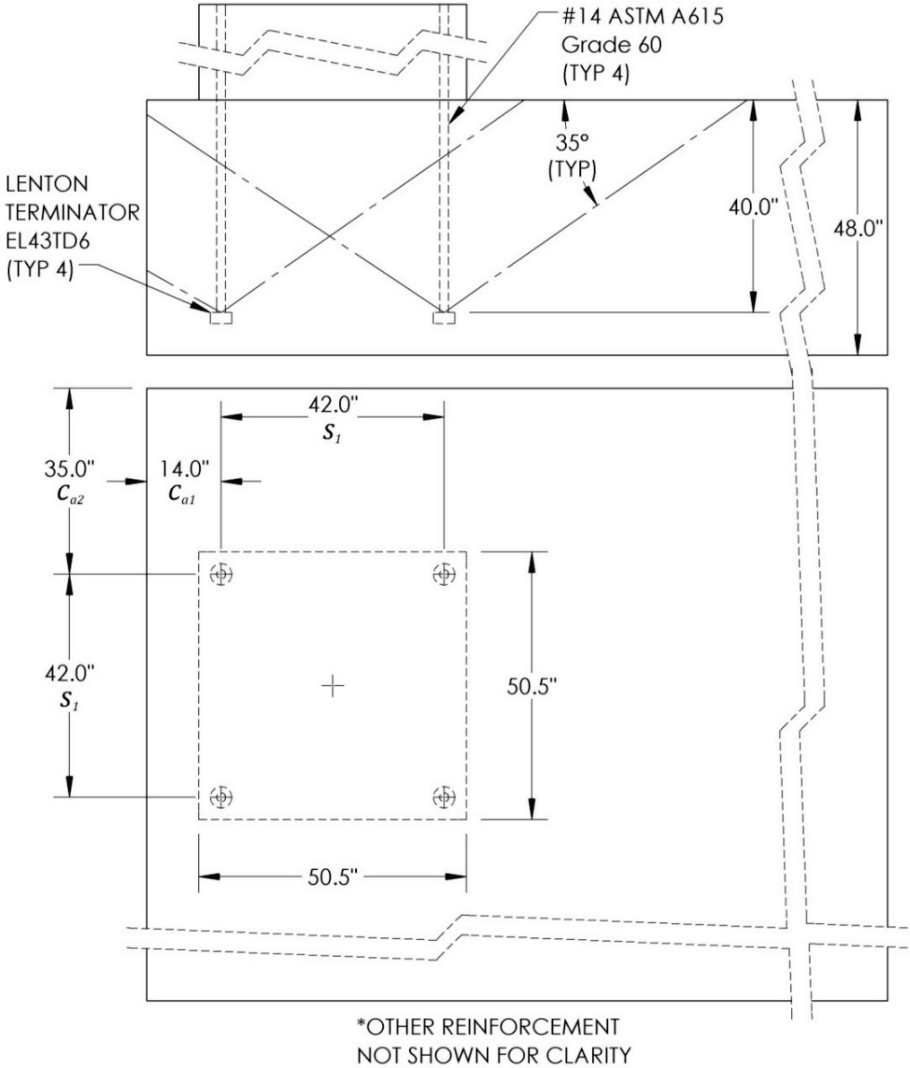
Summary:

- $\phi N_{cb} \geq N_{ua}$ (130,479 lbf \geq 62,400 lbf).
- $\phi N_{cbg} \geq N_{ua,g}$ (249,737 lbf \geq 249,600 lbf).
- $\phi N_{pn} \geq N_{ua}$ (211,210 lbf \geq 62,400 lbf).
- Evaluation of the side-face blowout strength (N_{sb}) is not required.

For additional information and useful references regarding designing with headed reinforcing bars, refer Appendix C of this design aid.

Example B2, Group of anchors with #14 Grade 60 rebar (close proximity to an edge)

An engineer’s design includes four nVent LENTON Terminator EL43TD6 rebar anchors to be used with #14 ASTM A615 Grade 60 rebar to anchor a cast in place column to a mat foundation. *Note that Section 17.3.2.2 of ACI 318-14 (D.4.2.2 of ACI 318-11) permits use of anchor diameters up to 4 inches.* The Terminators are configured as shown in the image below. Evaluating the anchor group to Chapter 17 of ACI 318-14 (Appendix D of ACI 318-11) enables the calculation of concrete breakout strength in tension for a single anchor (N_{cb}) or a group of anchors (N_{cbg}), pullout strength in tension (N_{pn}), and concrete side-face blowout strength in tension for a single anchor (N_{sb}) or a group of anchors (N_{sbg}) to ensure that the calculated performance meets the design’s factored tensile force of 270,000 lbf for the group of anchors ($N_{ua,g}$), and 67,500 lbf for a single anchor (N_{ua}).



Note that the anchors in this example meet the definition of an anchor group (defined as "a number of similar anchors having approximately equal effective embedment depths with spacing between adjacent anchors such that the projected areas overlap," reference Section 2.3 of ACI 318-14 (Section D.1 of ACI 318-11)). Furthermore, due to the proximity to edges, additional factors must be considered compared to Example B1 in this design aid.

Concrete Breakout Strength in Tension of a Single Anchor (N_{cb}): Breakout strength in tension can be calculated for a single anchor with the equation found in Section 17.4.2.1a of ACI 318-14 (D.5.2.1a of ACI 318-11).

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

To start, the variable of A_{Nc} must be determined according to Section 17.4.2.1 of ACI 318-14 (D.5.2.1 of ACI 318-11). As there are four anchors in this configuration, the anchor with the smallest projected concrete failure area is selected for evaluation. A_{Nc} is calculated as shown below (values for each variable can be found in the diagram at the beginning of this example):

$$A_{Nc} = (c_{a1} + 1.5h_{ef})(c_{a2} + 1.5h_{ef})$$

Symbol	Value	Unit	ACI 318 -14	ACI 318 -11	Description
c_{a1}	14	in	R17.4.2.1	RD.5.2.1	Minimum edge distance to center of anchor.
h_{ef}	40	in	-	-	Effective embedment depth of anchor.
c_{a2}	35	in	R17.4.2.1	RD.5.2.1	Distance from center of anchor to edge of concrete.

$$A_{Nc} = (14 \text{ in} + 1.5(40 \text{ in}))(35 \text{ in} + 1.5(40 \text{ in}))$$

$$A_{Nc} = 7,030 \text{ in}^2$$

A_{Nco} is determined by the equation 17.4.2.1c of ACI 318-14 (D-5 of ACI 318-11).

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

$$A_{Nco} = 9(40 \text{ in})^2$$

$$A_{Nco} = 14,400 \text{ in}^2$$

As $c_{a,min}$ is less than $1.5h_{ef}$

$$c_{a,min} < 1.5h_{ef}^2$$

$$14 \text{ in} < 1.5(40 \text{ in})$$

$$14 \text{ in} < 60 \text{ in}$$

The strength reduction factor of $\psi_{ed,N}$ (reference equation 17.4.2.5b of ACI 318-14 (D.5.2.5 of ACI 318-11)) is calculated by the following (for h_{ef} and $c_{a,min}$ values, refer to the diagram at the beginning of this example):

$$\psi_{ed,N} = 0.7 + 0.3 \frac{c_{a,min}}{1.5h_{ef}}$$

$$\psi_{ed,N} = 0.7 + 0.3 \frac{14 \text{ in}}{1.5(40 \text{ in})}$$

$$\psi_{ed,N} = 0.77$$

¹ $c_{a,min}$ is defined as the “minimum distance from center of an anchor shaft to the edge of concrete” per Section 2.2 of ACI 318-14 (2.1 of ACI 318-11), refer to the diagram at the beginning of this example.

As the effective embedment of the anchor (h_{ef}) is greater than 25 in, N_b is calculated from equation 17.4.2.2a of ACI 318-14 (D-6 of ACI 318-11).

$$N_b = k_c \lambda_a \sqrt{f'_c} h_{ef}^{3/2}$$

Symbol	Value	Unit	ACI 318 -14	ACI 318 -11	Description
k_c	24	-	17.4.2.2	D.5.2.2	Coefficient for basic concrete breakout strength in tension.
λ_a	1.0	-	17.2.6	D.3.6	Modification factor for lightweight concrete, normalweight = 1.0.
f'_c	4,000	psi	-	-	Specified compressive strength of concrete.
h_{ef}	40.0	in	-	-	Effective embedment depth of anchor.

$$N_b = 24(1.0)\sqrt{4,000 \text{ psi}} (40 \text{ in})^{3/2}$$

$$N_b = 384,000 \text{ lbf}$$

With each of the variables and reduction factors known in equation 17.4.2.1a of ACI 318-14 (D-3 of ACI 318-11), N_{cb} can be solved for.

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

Symbol	Value	Unit	ACI 318 -14	ACI 318 -11	Description
A_{Nc}	7,030	in ²	R17.4.2.1 & 17.4.2.3	RD.5.2.1 & D.5.2.3	Projected concrete failure area of a single anchor, reduced by edges.
A_{Nco}	14,400	in ²	17.4.2.1	D.5.2.1	Projected concrete failure area of a single anchor not limited by edge or spacing.
A_{Nc}/A_{Nco}	0.488	-	R17.4.2.1	RD.5.2.1	Actual projected failure area for a single anchor (A_{Nc}) divided by theoretical projected failure area (A_{Nco}).
$\psi_{ed,N}$	0.77	-	17.4.2.5	D.5.2.5	Modification factor for edge proximity, when not affected by edge, set equal to 1.0.
$\psi_{c,N}$	1.25	-	17.4.2.6	D.5.2.6	Modification factor based on presence or absence of cracks, 1.25 for no cracks.
$\psi_{cp,N}$	1.0	-	17.4.2.7	D.5.2.7	Modification factor for post-installed anchors, set equal to 1.0 for cast-in anchors.
N_b	384,000	lbf	17.4.2.2	D.5.2.2	Basic concrete breakout strength in tension of single anchor.

$$N_{cb} = (0.488)(0.77)(1.25)(1.0)(384,000 \text{ lbf})$$

$$N_{cb} = 180,365 \text{ lbf}$$

According to Section 17.3.1.1 of ACI 318-14 (D.4.1.1 of ACI 318-11), the concrete breakout strength of a single anchor (N_{cb}) multiplied by the strength reduction factor (ϕ) must be greater than or equal to the factored tensile force applied to the anchor (N_{ua}).

$$\phi N_{cb} \geq N_{ua}$$

Symbol	Value	Unit	ACI 318 -14	ACI 318 -11	Description
ϕ	0.70	-	17.3.3(c)	D.4.3(c)	Strength reduction factor for anchors governed by concrete breakout, when supplementary reinforcement is not present (Condition B).
N_{cb}	180,365	lbf	17.3.1.1 & 17.4.2.1	D.4.1.1 & D.5.2.1	Nominal concrete breakout strength in tension of a group of anchors.
N_{ua}	67,500	lbf	-	-	Factored tensile force applied to anchor or group of anchors.

$$(0.70)(180,365 \text{ lbf}) \geq 67,500 \text{ lbf}$$

$$126,255 \text{ lbf} \geq 67,500 \text{ lbf}$$

Concrete Breakout Strength in Tension of Group of Anchors (N_{cbg}): Breakout strength in tension can be calculated for a group of anchors with the equation found in Section 17.4.2.1b of ACI 318-14 (D.5.2.1b of ACI 318-11).

$$N_{cgb} = \frac{A_{Nc}'}{A_{Nco}} \psi_{ec,N} \psi_{ed,N} \psi_{c,N} \psi_{cp,N} N_b$$

To start, the variable of A_{Nc}' (A_{Nc}' is used in this design aid to represent a group of anchors, where A_{Nc} is used to represent a single anchor) must be determined according to Section 17.4.2.1 of ACI 318-14 (D.5.2.1 of ACI 318-11). In this scenario, two of the four edges are located less than $1.5h_{ef}$ from the respective anchor center, therefore, A_{Nc}' is calculated as shown below (values for each variable can be found in the diagram at the beginning of this example):

$$A_{Nc}' = (c_{a1} + s_1 + 1.5h_{ef})(c_{a2} + s_1 + 1.5h_{ef})$$

Symbol	Value	Unit	ACI 318 -14	ACI 318 -11	Description
c_{a1}	14	in	R17.4.2.1	RD.5.2.1	Minimum edge distance to center of anchor.
s_1	42	in	R17.4.2.1	RD.5.2.1	Center to center spacing of anchors.
h_{ef}	40	in	-	-	Effective embedment depth of anchor.
c_{a2}	35	in	R17.4.2.1	RD.5.2.1	Distance from center of anchor to edge of concrete.

$$A_{Nc}' = (14 \text{ in} + 42 \text{ in} + 1.5(40 \text{ in}))(35 \text{ in} + 42 \text{ in} + 1.5(40 \text{ in}))$$

$$A_{Nc}' = 15,892 \text{ in}^2$$

A_{Nco} is determined by the equation 17.4.2.1c of ACI 318-14 (D-5 of ACI 318-11).

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

$$A_{Nco} = 9(40 \text{ in})^2$$

$$A_{Nco} = 14,400 \text{ in}^2$$

With each of the variables and reduction factors known in equation 17.4.2.1b of ACI 318-14 (D-4 of ACI 318-11), N_{cgb} can be calculated.

$$N_{cgb} = \frac{A_{Nc'}}{A_{Nco}} \psi_{ec,N} \psi_{ed,N} \psi_{c,N} \psi_{cp,N} N_b$$

Symbol	Value	Unit	ACI 318 -14	ACI 318 -11	Description
A_{Nc}'	15,892	in ²	R17.4.2.1 & 17.4.2.3	RD.5.2.1 & D.5.2.3	Projected concrete failure area of a group of anchors.
A_{Nco}	14,400	in ²	17.4.2.1	D.5.2.1	Projected concrete failure area of a single anchor not limited by edge or spacing.
A_{Nc}'/A_{Nco}	1.103	-	R17.4.2.1	RD.5.2.1	Actual projected failure area of the group of anchors (A_{Nc}') divided by theoretical projected failure area (A_{Nco}).
$\psi_{ec,N}$	1.0	-	17.4.2.4	D.5.2.4	Modification factor for anchor groups loaded eccentrically in tension, set equal to 1.0 if load is centered in anchor group.
$\psi_{ed,N}$	0.77	-	17.4.2.5	D.5.2.5	Modification factor for edge proximity, when not affected by edge, set equal to 1.0.
$\psi_{c,N}$	1.25	-	17.4.2.6	D.5.2.6	Modification factor based on presence or absence of cracks, 1.25 for no cracks.
$\psi_{cp,N}$	1.0	-	17.4.2.7	D.5.2.7	Modification factor for post-installed anchors, set equal to 1.0 for cast-in anchors.
N_b	384,000	lbf	17.4.2.2	D.5.2.2	Basic concrete breakout strength in tension of single anchor

$$N_{cgb} = (1.103)(1.0)(0.77)(1.25)(1.0)(384,000 \text{ lbf})$$

$$N_{cgb} = 407,669 \text{ lbf}$$

According to Section 17.3.1.1 of ACI 318-14 (D.4.1.1 of ACI 318-11), the concrete breakout strength of a group of anchors (N_{cbg}) multiplied by the strength reduction factor (ϕ) must be greater than or equal to the factored tensile force applied to the group of anchors ($N_{ua,g}$).

$$\phi N_{cbg} \geq N_{ua,g}$$

Symbol	Value	Unit	ACI 318 -14	ACI 318 -11	Description
ϕ	0.70	-	17.3.3(c)	D.4.3(c)	Strength reduction factor for anchors governed by concrete breakout, when supplementary reinforcement is not present (Condition B).
N_{cbg}	407,669	lbf	17.3.1.1 & 17.4.2.1	D.4.1.1 & D.5.2.1	Nominal concrete breakout strength in tension of a group of anchors.
$N_{ua,g}$	270,000	lbf	-	-	Factored tensile force applied to anchor or group of anchors.

$$(0.70)(407,669 \text{ lbf}) \geq 270,000 \text{ lbf}$$

$$285,368 \text{ lbf} \geq 270,000 \text{ lbf}$$

In cases where the nominal breakout strength does not meet the required load, the engineer may consider increasing variables such as: anchor spacing, distance from anchor to concrete edge, effective embedment depth, bearing area of the anchor (Section 17.4.2.8 of ACI 318-14 or D.5.2.8 of ACI 318-11), and/or concrete compressive strength. Other considerations may include the addition of supplemental reinforcement (Section 17.3.3 of ACI 318-14 or D.4.3 of ACI 318-11), the inclusion of anchor reinforcement, and/or altering the relationship between the effective embedment depth and d (ACI 318 defines d as the "distance from extreme compression fiber to centroid of longitudinal tension reinforcement, in."), such that the effective embedment depth is greater than $(1.5)(d)$ – precluding breakout failure, refer to Section 17.4.2.9 of ACI 318-14 or D.5.2.9 of ACI 318-11. Also see Appendix C of this design aid for additional information and useful references.

Pullout Strength of Cast-in Anchor in Tension (N_{pn}): The nominal pullout strength of a single cast-in anchor (N_{pn}) can be calculated from the equations found in Section 17.4.3 of ACI 318-14 (D.5.3 of ACI 318-11) by substituting for N_p (pullout strength of a single anchor in cracked concrete), as shown below. Note that N_{pn} is representative of the load at which initial crushing of the concrete occurs, not the load required to pull the anchor out of the concrete entirely, reference Section R17.4.3.4 of ACI 318-14 (RD.5.3.4 of ACI 318-11).

$$N_{pn} = \psi_{c,P} N_p \quad N_p = 8A_{brg} f'_c$$

$$N_{pn} = \psi_{c,P} 8A_{brg} f'_c$$

Symbol	Value	Unit	ACI 318-14	ACI 318-11	Description
$\psi_{c,P}$	1.4	in ²	17.4.3.6	D.5.3.6	Modification factor based on presence or absence of cracks, set equal to 1.4 for no cracks, 1.0 for cracking at service load levels.
A_{brg}	10.316	in ²	-	-	Net bearing area of EL43TD6 Terminator.
f'_c	4,000	psi	-	-	Specified compressive strength of concrete.

$$N_{pn} = 462,157 \text{ lbf}$$

$$N_{pn} = (1.4)(8)(10.316 \text{ in}^2)(4,000 \text{ psi})$$

Even when the strength reduction factor (ϕ) of 0.70 is multiplied by N_{pn} , the result is still well above the factored tensile load applied to a single anchor (N_{ua}). Reference Sections 17.3.3 of ACI 318-14 (D.4.3 of ACI 318-11) and 17.3.1.1 of ACI 318-14 (D4.1.1 of ACI 318-11).

$$\phi N_{pn} \geq N_{ua}$$

$$(0.70)(462,157 \text{ lbf}) \geq 67,500 \text{ lbf}$$

$$323,510 \text{ lbf} \geq 67,500 \text{ lbf}$$

Side-Face Blowout Strength of a Headed Anchor in Tension (N_{sb}): For anchors with an effective embedment depth (h_{ef}) greater than $2.5(c_{a1})$,

$$h_{ef} > 2.5c_{a1}$$

$$40 \text{ in} > 2.5(14 \text{ in})$$

$$40 \text{ in} > 35 \text{ in}$$

The side-face blowout strength of a headed anchor in tension should be evaluated to the following equation from Section 17.4.4 of ACI 318-14 (D.5.4 of ACI 318-11), where N_{sb} is for a single anchor.

$$N_{sb} = 160c_{a1}\sqrt{A_{brg}}\lambda_a\sqrt{f'_c}$$

$$N_{sb} = 160(14 \text{ in})\sqrt{10.316 \text{ in}}(1.0)\sqrt{4,000 \text{ psi}}$$

$$N_{sb} = 455,023 \text{ lbf}$$

With N_{sb} calculated, it can be compared to the factored design load, reference Section 17.3.3 of ACI 318-14 (D.4.3 of ACI 318-11) as well as Section 17.3.1.1 of ACI 318-14 (D4.1.1 of ACI 318-11).

$$\phi N_{sb} \geq N_{ua}$$

$$0.7(455,023 \text{ lbf}) \geq 67,500 \text{ lbf}$$

$$318,516 \text{ lbf} \geq 67,500 \text{ lbf}$$

As can be seen above, for an individual anchor located at the distance of c_{a1} from the nearest edge, the resistance to a side-face blowout failure is sufficient. However, as one of the four anchors (reference the diagram at the beginning of this example) has a dimension c_{a2} less than $3c_{a1}$,

$$c_{a2} < 3c_{a1}$$

$$35 \text{ in} < 3(14 \text{ in})$$

$$35 \text{ in} < 42 \text{ in}$$

N_{sb} must be multiplied by a strength reduction factor when

$$1.0 \leq \frac{c_{a2}}{c_{a1}} \leq 3.0$$

$$1.0 \leq \frac{35 \text{ in}}{14 \text{ in}} \leq 3.0$$

$$1.0 \leq 2.5 \leq 3.0.$$

Under these circumstances, N_{sb}' is solved for as follows (according to Section 17.4.4.1 of ACI 318-14 (D.5.4.1 of ACI 318-11)):

$$N_{sb}' = N_{sb} \left(\frac{1 + c_{a2}/c_{a1}}{4} \right)$$

$$N_{sb}' = 455,023 \text{ lbf} \left(\frac{1 + 35 \text{ in}/14 \text{ in}}{4} \right)$$

$$N_{sb}' = 398,145 \text{ lbf}$$

With N_{sb}' calculated, it can be compared to the factored design load, reference Sections 17.3.3 of ACI 318-14 (D.4.3 of ACI 318-11) and 17.3.1.1 of ACI 318-14 (D4.1.1 of ACI 318-11).

$$\phi N_{sb}' \geq N_{ua}$$

$$0.7(398,145 \text{ lbf}) \geq 67,500 \text{ lbf}$$

$$278,702 \text{ lbf} \geq 67,500 \text{ lbf}$$

The side-face blowout for the group of anchors (N_{sbg}) can be evaluated by following Section 17.4.4.2 of ACI 318-14 (D.5.4.2 of ACI 318-11)). As anchor spacing (s) is less than $6c_{a1}$,

$$s_1 < 6c_{a1}$$

$$42 \text{ in} < 6(14 \text{ in})$$

$$42 \text{ in} < 84 \text{ in}$$

the following equation is used for N_{sbg} (when calculating N_{sbg} , use N_{sb} , not N_{sb}'):

$$N_{sbg} = \left(1 + \frac{s_1}{6c_{a1}}\right) N_{sb}$$

$$N_{sbg} = \left(1 + \frac{42 \text{ in}}{6(14 \text{ in})}\right) 455,023 \text{ lbf}$$

$$N_{sbg} = 682,535 \text{ lbf}$$

With the side-face blowout strength of the group of anchors (qty 2) at a distance of c_{a1} known, it can be compared to the factored tensile load applied specifically to those same anchors---not the factored tensile load of the entire anchor group (qty 4), reference Section R14.4.4.2 of ACI 318-14 (RD5.4.2 of ACI 318-11). In this example, $N_{ua,g}'$ is 50% of the total factored tensile load.

$$\phi N_{sbg} \geq N_{ua,g}'$$

$$(0.70)(682,535 \text{ lbf}) \geq 135,000 \text{ lbf}$$

$$477,775 \text{ lbf} \geq 135,000 \text{ lbf}$$

Summary:

- $\phi N_{cb} \geq N_{ua}$ (126,255 lbf \geq 67,500 lbf).
- $\phi N_{cbg} \geq N_{ua,g}$ (285,386 lbf \geq 270,000 lbf).
- $\phi N_{pn} \geq N_{ua}$ (323,510 lbf \geq 67,500 lbf).
- $\phi N_{sb} \geq N_{ua}$ (318,516 lbf \geq 67,500 lbf).
- $\phi N_{sb}' \geq N_{ua}$ (278,702 lbf \geq 67,500 lbf).
- $\phi N_{sbg} \geq N_{ua,g}'$ (477,775 lbf \geq 135,000 lbf).

For additional information and useful references regarding designing with headed reinforcing bars, refer Appendix C of this design aid.

Appendix A: Development length tables for standard hooks and headed reinforcing bars

Development Lengths (l_{dh}) for <u>Hooked</u> Bars per Section 25.4.3 of ACI 318-14 (12.5 of ACI 318-11), inch					
Bar Size		Concrete Compressive Strength, psi			
ASTM	mm	3,000	4,000	5,000	6,000
#4	12	11.0	9.5	8.5	7.7
#5	16	15.3	13.3	10.6	9.7
#6	20	16.4	14.2	12.7	11.6
#7	22	19.2	16.6	14.8	13.6
#8	25	21.9	19.0	17.0	15.5
#9	28	24.7	21.4	19.1	17.5
#10	32	27.8	24.1	21.6	19.7
#11	36	30.9	26.8	23.9	21.8

Calculations based on 60 ksi (yield) black bar, normalweight concrete, and cover and reinforcement reduction factors set to 1.0.

Development Lengths (l_{dt}) for <u>Headed</u> Bars per Section 25.4.4 of ACI 318-14 (12.6 of ACI 318-11), inch					
Bar Size		Concrete Compressive Strength, psi			
ASTM	mm	3,000	4,000	5,000	6,000
#4	12	8.8	7.6	6.8	6.2
#5	16	11.0	9.5	8.5	7.7
#6	20	13.1	11.4	10.2	9.3
#7	22	15.3	13.3	11.9	10.8
#8	25	17.5	15.2	13.6	12.4
#9	28	19.8	17.1	15.3	14.0
#10	32	22.3	19.3	17.2	15.7
#11	36	24.7	21.4	19.1	17.5

Calculations based on 60 ksi (yield) black bar and normalweight concrete, assuming that all conditions in 25.4.4.1 (ACI 318-14) are met.

Appendix B: Solving for h_{ef}

Chapter 17 of ACI 318-14 (Appendix D of ACI 318-11) enables the calculation of required effective embedment depths of anchors in concrete to ensure that the effective embedment in concrete is sufficient to develop the necessary force in the reinforcing bar.

The following is an example of how the effective embedment depth (h_{ef}) for a single anchor is solved for from the relevant equations for concrete breakout strength in Chapter 17.

Equation	ACI 318-14	ACI 318-11
$\phi N_{cb} \geq N_{ua}$	17.3.1.1	D.4.1.1
$N_{cb} = \frac{A_{Nc}}{A_{Nco}} \psi_{ed,N} \psi_{c,N} \psi_{cp,N} N_b$	17.4.2.1a	Eq. D-3 (D.5.2.1)
$N_b = k_c \lambda_a \sqrt{f'_c} h_{ef}^{3/2}$	17.4.2.2a	Eq. D-6 (D.5.2.2)
$N_b = 16 \lambda_a \sqrt{f'_c} h_{ef}^{5/3}$	17.4.2.2b	Eq. D-7 (D.5.2.2)

Replace N_b in the equation 17.4.2.1a with equation 17.4.2.2a or 17.4.2.2b (if 17.4.2.2a is overly conservative) per R17.4.2.2 of ACI 318-14 (RD.5.2.2 of ACI 318-11).

$$N_{cb} = \frac{A_{Nc}}{A_{Nco}} \psi_{ed,N} \psi_{c,N} \psi_{cp,N} k_c \lambda_a \sqrt{f'_c} h_{ef}^{3/2}$$

Solve for N_{cb} in equation 17.3.1.1 and substitute into N_{cb} as found in the combination of equations 17.4.2.1a and 17.4.2.2a, as shown above.

$$\frac{N_{ua}}{\phi} = \frac{A_{Nc}}{A_{Nco}} \psi_{ed,N} \psi_{c,N} \psi_{cp,N} k_c \lambda_a \sqrt{f'_c} h_{ef}^{3/2}$$

Solve for h_{ef} .

$$h_{ef} = \left[\frac{N_{ua}}{\phi \frac{A_{Nc}}{A_{Nco}} \psi_{ed,N} \psi_{c,N} \psi_{cp,N} k_c \lambda_a \sqrt{f'_c}} \right]^{2/3}$$

For cases when h_{ef} is greater than or equal to 11 in, and less than or equal to 25 in and 17.4.2.2a is deemed as overly conservative (Section 17.4.2.2 of ACI 318-14 (RD.5.2.2 of ACI 318-11)), the following can be used to solve for h_{ef} (solved after the same manner as demonstrated above, except that equation 17.4.2.2.b is substituted into equation 17.4.2.1.a).

$$h_{ef} = \left[\frac{N_{ua}}{\phi \frac{A_{Nc}}{A_{Nco}} \psi_{ed,N} \psi_{c,N} \psi_{cp,N} k_c 16 \lambda_a \sqrt{f'_c}} \right]^{3/5}$$

Appendix C: Additional Information, references to supplementary resources and literature

When designing with headed bars to ACI 318, an engineer may encounter scenarios where using headed bars in place of hooks is the logical and perhaps the only viable option, but the standard calculation methods of ACI 318-14 Chapter 17 (Appendix D of ACI 318-11) result in numbers that are much less favorable than if using the standard calculation methods associated with hooks. For example, calculating the concrete breakout strength of a group of anchors according to Section 17.4.2 of ACI 318-14 (Section D.5.2 of ACI 318-11) will not factor the benefit of anchor reinforcement. This often results in concrete breakout strengths lower than required. The following sections of the code are found useful for working to a solution in such scenarios:

- According to R17.3.2.1 of ACI 318-14 (RD.4.2.1 of ACI 318-11), "The effect of reinforcement is not included in the...concrete breakout calculation method of 17.4.2 and 17.5.2...**Anchor reinforcement may be provided instead of calculating breakout strength** using the provisions of Chapter 25 in conjunction with 17.4.2.9 and 17.5.2.9."
- R25.4.4.2 of ACI 318-14 (states "Where closely spaced headed bars are used, the potential for concrete breakout failure exists. For joints as shown in Fig. R25.4.4.2c and R25.4.4.2d, **concrete breakout failure can be precluded** by providing anchorage length equal to or greater than $d/1.5$ (Eligehausen 2006b), as shown in Fig. R25.4.4.2c, or by **providing reinforcement in the form of hoops and ties to establish a load path in accordance with strut-and-tie modeling principles**, as shown in Fig. R25.4.4.2d. Strut-and-tie models should be verified in accordance with Chapter 23."
- Section 17.4.2.9 of ACI 318-14 (D.5.2.9 of ACI 318-11) states "Where **anchor reinforcement** is developed in accordance with Chapter 25 on both sides of the breakout surface, the design strength of the anchor reinforcement shall be permitted to be used instead of the concrete breakout strength in determining ϕN_r ."
- Regarding considerations for seismic design, Section 17.2.3.4.4 of ACI 318-14 (D.3.3.4.4 of ACI 318-11) states: "... N_{cb} or N_{cbg} need not be calculated where anchor reinforcement satisfying 17.4.2.9 is provided;"
- Section 4.5.3.1 of ACI 352R states "The use of headed reinforcement **in place of standard hooks**, particularly in disturbed regions of a concrete member with

nonlinear strain distribution, is a viable option and presents no significant design problems (Wallace 1997; Berner and Hoff 1994)."

- R25.4.5.1 of ACI 318-14 (R12.6.4 of ACI 318-11), states "Anchorage of deformed bars through the use of mechanical devices within concrete that do not meet the requirements in 20.2.1.6, or are not developed in accordance with 25.4.4, **may be used if tests demonstrate** the ability of the head and bar system to develop or anchor the desired force in the bar, as described in this provision."

In addition, numerous published studies have been carried out to determine the actual performance of headed reinforcing bars in concrete members, some of these are listed below:

1. Kang, T. H.-K.; Kim, W.; and Shin, M., 2012, "Cyclic Testing for Seismic Design Guide of Beam-Column Joints with Closely Spaced Headed Bars," *Journal of Earthquake Engineering*, V. 16, pp. 211–230.
2. Kang, T. H.-K.; Shin, M.; Mitra, M., and Bonacci, J. F., 2009, "Seismic Design of Reinforced Concrete Beam-Column Joints with Headed Bars," *ACI Structural Journal*, V. 106, pp. 868–877.
3. Lam, K. M.; Kim, W.; Zandt, M. V.; and Kang, T. H., 2011. "An Experimental Study of Reinforced Concrete Beams with Closely-Spaced Headed Bars," *International Journal of Concrete Structures and Materials*, V. 5, pp. 77–85.
4. Mihaylov, B. I.; Bentz, E. C.; and Collins, M. P.; 2013, "Behavior of Deep Beams with Large Headed Bars," *ACI Structural Journal*, V. 110.
5. Ou, Y.-C.; Canseco, H. A.; and Kurniawan, D. P., 2017, "Anchorage Performance of Headed Deformed Bars in Exterior Beam-Column Joints under Cyclic Loading," *KSCE Journal of Civil Engineering*, V. 21, No. 7, pp. 2837–2849.
6. Shao, Y.; Darwin, D.; O'Reilly, M.; Lequesne, R. D.; Ghimire, K.; and Hano, M., 2018. "Anchorage of Conventional and High-Strength Headed Reinforcing Bars," *The University of Kansas Center for Research, Inc*, SM Report No. 117, pp. 234.
7. Thompson, M.; Ziehl, M.; Jirsa, J.; and Breen, J., 2005. "CCT Nodes Anchored by Headed Bars - Part 1: Behavior of nodes," *ACI Structural Journal*, V. 102, pp. 808–815.
8. Thompson, M. K.; Jirsa, J. O.; and Breen, J. E., 2006. "CCT Nodes Anchored by Headed Bars - Part 2: Capacity of Nodes," *ACI Structural Journal*, V. 103.
9. Wallace, J. W.; McConnell, S. W.; Gupta, P.; and Cote, P. A., 1998, "Use of Headed Reinforcement in Beam-Column Joints Subjected to Earthquake Loads," *ACI Structural Journal*, V. 95.

And lastly, relevant technical reviews and summaries on headed bars are listed below:

1. Concrete Reinforcing Steel Institute, 2014, "Frequently Asked Questions (FAQ) about Headed Reinforcing Bars," *CRSI*, CRSI Technical Note ETN-M-3-14.
2. Concrete Reinforcing Steel Institute, 2018, "Reinforcing Bars: Anchorages and Splices 6th Edition," *CRSI*.

Appendix D: Frequently Asked Questions

CONTENT:

1. CODES, COMPLIANCE, AND APPROVALS
2. SIZE, DEVELOPMENT, SPACING, AND COVER
3. INSTALLATION
4. OTHER

1. CODES, COMPLIANCE, AND APPROVALS:

1.1. **Q:** What sections of the ACI code govern the use of headed bars?

A: Section 25.4.4 of ACI 318-14 (Section 12.6 of ACI 318-11) governs the development length and use of headed and mechanically-anchored deformed bars in tension. Headed bars must satisfy Section 20.2.1.6 and 25.4.4.1 of ACI 318-14 (Section 3.5.9 and 12.6.1 of ACI 318-11). When conditions do not meet the requirements in Section 25.4.4.1, Section 17.4.1 of ACI 318-14 (Appendix D of ACI 318-11) can be utilized.

1.2. **Q:** Does the nVent LENTON Terminator comply with Section 20.2.1.6 of ACI 318-14 (3.5.9 of ACI 318-11)?

A: Yes.

1.3. **Q:** Does the Terminator comply with ACI 318 and ASTM A970?

A: Yes, the D6, D16, and D14 Terminators comply with ACI 318 and ASTM A970, including Class HA requirements.

1.4. **Q:** Does the net bearing area of the Terminator comply with Section 25.4.4.1(d) of ACI 318-14 (12.6.1(d) of ACI 318-11)?

A: Yes, the net bearing area of D6 and D16 Terminator heads (A_{brg}) is at least 4 times the area of the bar ($4A_b$). The D14 Terminator is at least $9A_b$.

1.5. **Q:** Does the Terminator meet ACI 318 Type 1 and Type 2 splice requirements?

A: Yes.

1.6. **Q:** Is the Terminator covered under a evaluation report(s)?

A: Yes, IAMPO-UES 0188, also the ICC-ES Legacy Report #3967 can be used for reference.

2. SIZE, DEVELOPMENT, SPACING, AND COVER:

2.1. **Q:** Can the Terminator be used with reinforcing bar of sizes greater than #11?

A: Yes, when using rebar sizes greater than #11, refer to Sections 17.4 and 17.3.2.2 of ACI 318-14 (Appendix D and Section D.4.2.2 of ACI 318-11).

2.2. **Q:** Can the reinforcing bar be developed in a shorter development length when using the Terminator compared to a standard hook?

A: Yes, refer to the nVent LENTON Headed Bar and Mechanical Anchor Design Aid and Sections 25.4.3 and 25.4.4 of ACI 318-14 (12.5 and 12.6 of ACI 318-11).

2.3. **Q:** Will the Terminator develop the strength of the bar?

A: When properly installed, the Terminator will develop 100% of the specified tensile strength of ASTM A615 grades 60/75/80 and ASTM A706 grades 60/80 rebar.

2.4. **Q:** How is development length calculated when using the Terminator?

A: When conditions in Section 25.4.4.1 of ACI 318-14 are met (12.6.1 of ACI 318-11), the development length for a Terminator can be calculated by following Section 25.4.4.2 of ACI 318-14 (12.6.2 of ACI 318-11). When any condition in Section 25.4.4.1 is not met, Section 17.4 of ACI 318-14 (Appendix D of ACI 318-11) may be utilized.

2.5. **Q:** Can I add the contribution of the bond of the rebar to the bearing of the head?

A: Yes, the development lengths determined by Section 25.4.4 of ACI 318-14 (12.6 of ACI 318-11) are a combination of the bearing force at the head and bond forces along the reinforcing bar.

2.6. **Q:** What special considerations must be taken when performing calculations for a group of closely spaced Terminators?

A: When bar spacing and clearance requirements of Section 25.4.4.1 of ACI 318-14 (12.6.1 of ACI 318-11) are satisfied, ACI does not distinguish a difference in calculating one versus multiple headed bars when determining development lengths from Section 25.4.4.2 (12.6.2 of ACI 318-11). However, when evaluating effective embedment depths according to Section 17.4 of ACI 318-14 (Appendix D of ACI 318-11), a group of anchors is analyzed differently than a single anchor. See the examples provided in the nVent LENTON Headed Bar and Mechanical Anchor Design Aid.

2.7. **Q:** How close can Terminators be spaced?

A: The minimum clear spacing between BARS of mechanically anchored bars is $4d_b$ as stated in Section 25.4.4.1(g) of ACI 318-14 (12.6.1(f) of ACI 318-11). Clear spacing requirements listed in this section are based on dimensions measured to the bar, not to the head. Using a Terminator at the minimum clear spacing may cause adjacent edges of Terminators to touch. Touching of the heads is allowed; however, the heads may be staggered to eliminate any touching and/or congestion. Additionally, argument can be made for bar spacing of $3d_b$ based on Section 18.8.5.2 of ACI 318-14 (Joints of Special Moment Frames for Earthquake Resistant Structures).

2.8. **Q:** What is the minimum cover required for the Terminator?

A: The minimum cover required for the BAR of a mechanically anchored bar is $2d_b$ per Section 25.4.4.1(f) of ACI 318-14 (12.6.1(e) of ACI 318-11). Clear cover requirements listed in section 25.4.4.1(f) are based on dimensions measured to the bar, not to the head. Clear cover for a Terminator can be derived from Section 20.6.1 of ACI 318-14 (7.7 of ACI 318-11). The Terminator shall be considered to be part of the bar to satisfy cover requirements in Section 20.6.1.

3. INSTALLATION:

3.1. Q: Can the Terminator be welded?

A: No, the Terminator is not designed for structural welding applications. nVent LENTON offers a variety of weldable couplers, refer to www.erico.com. However, it should be noted that tack welding of the Terminator on the outside diameter for “positional purposes” is acceptable.

3.2. Q: Can a properly installed Terminator be removed and installed again at a later date?

A: Yes, properly installed nVent LENTON taper-threaded products (including the Terminator) may be removed at a later date and reinstalled; it is not a “single-use” system. So long as all nVent LENTON installation instructions are followed at each installation, performance will not be diminished.

3.3. Q: Why do Terminators for reinforcing bars larger than #11 (36 mm) have an adjoining collar with a smaller diameter?

A: The smaller diameter facilitates installation with a standard pipe wrench.

3.4. Q: Does each Terminator need to be installed with a torque wrench?

A: The Terminator can be installed with a standard commercial pipe wrench. Following the installation, an inspection wrench may be used to verify the tightness of the connection. The frequency of this verification step is determined by project specifications or the inspector. A typical scenario would be to check 1 out of the first 10 couplers, and if good assembly can be repeatedly demonstrated, 1 out of every 100 thereafter.

3.5. Q: After the Terminator is installed, how far can the face of the threaded end of the rebar extend beyond or be recessed below the face of the Terminator?

A: The permissible tolerance is +/- 2 threads.

4. OTHER:

4.1. **Q:** What is the difference between a D6, D16, and a D14 Terminator?

A: The D6 is the standard product in North America, while the D16 is the standard design for Europe. The D6 and D16 have the same outside diameter and provide the same bearing area. The D14 Terminator is designed with a much larger bearing area ($9A_b$) than the D6 and D16. This larger bearing area allows for the potential of developing a bar in a shorter length as compared to a D6 or D16. However, it should be noted that Section 25.4.4 of ACI 318-11 (12.6 of ACI 318-11) does not take this increased bearing area into account when determining development length. Therefore, the engineer should consult Section 17.4.1 of ACI 318-14 (Appendix D of ACI 318-11) for calculating the effective embedment depth and capacity when specifying the D14 Terminator.

4.2. **Q:** How should the Terminator be specified?

A1: Specific: Rebar terminations shall be nVent LENTON Terminator as manufactured by nVent LENTON.

A2: Generic: The rebar terminations shall meet building code requirements, as required, by local norms/codes. The rebar terminations shall be positive locking, taper threaded type anchor manufactured from high quality steel. The bar end must be taper threaded using the manufacturer's bar threading equipment to ensure proper taper and thread engagement. Bars shall be installed to the manufacturer's requirements. The anchors shall be manufactured using registered quality systems around the world.

4.3. **Q:** Besides ACI 318, where can additional design information and guidance on headed bars be found?

A: The nVent LENTON Headed Bar and Mechanical Anchor Design Aid.

A: PCA has a published document titled, "Notes on ACI 318-08 Building Code Requirements for Structural Concrete." Refer to Section 4, pages 8-10.

4.4. **Q:** How can technical information be obtained regarding the nVent LENTON Terminator?

A: Visit our website at www.erico.com or call 1-800-248-2677 to speak with technical support.

Appendix E: Application Pictures

Installation:



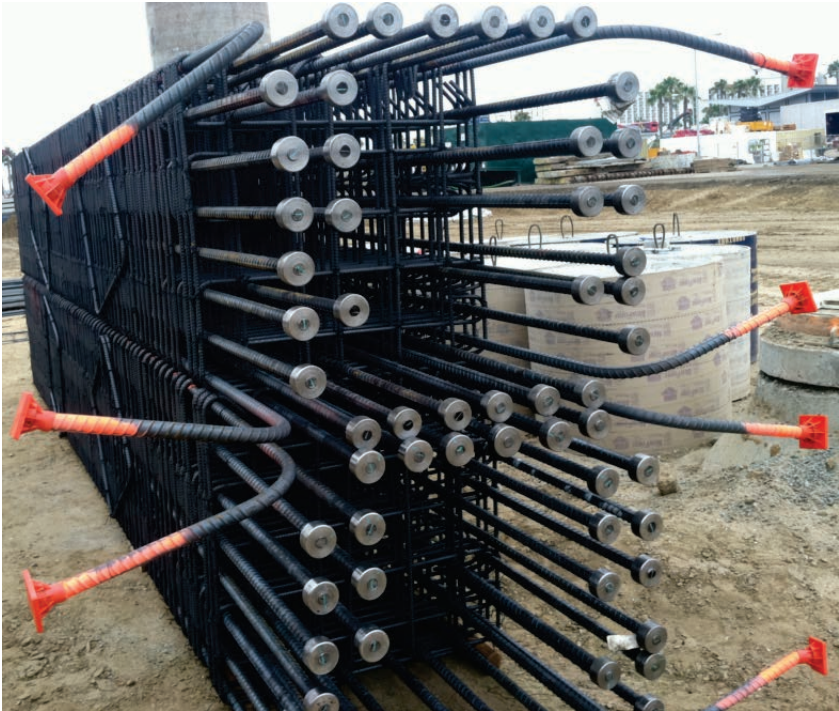
Beam to Column:



Columns, Piers, Pier Caps, and Piles:



Columns, Piers, Pier Caps, and Piles (continued):



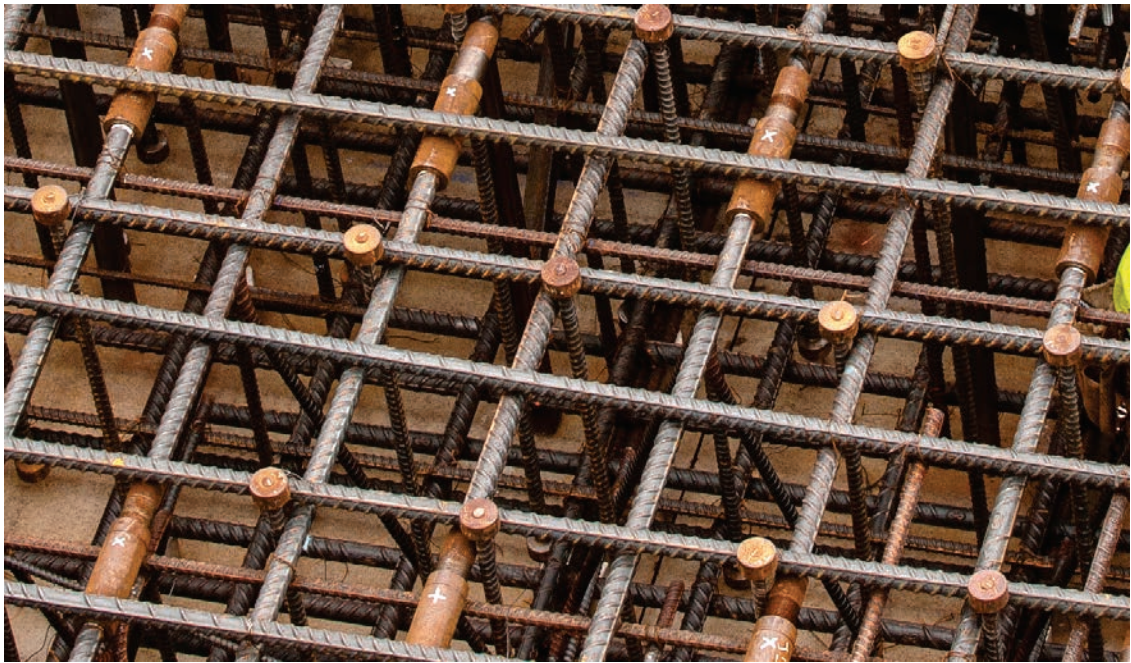
Segmental Construction:



Segmental Construction (continued):



Nuclear:



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