

**Report on Applicability of the  
Hilti Kwik Bolt-TZ Expansion Anchor  
for use in  
Components and Structural Supports  
in Nuclear Facilities**

A Review and Recommendation concerning testing compliance with USNRC General Design Criterion (GDC) 1, "Quality Standards and Records," of Appendix A, "General Design Criteria for Nuclear Power Plants," to 10 CFR Part 50, and Appendix B of ACI 349-01

Report WC 11-03

**Prepared for  
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## 1. Purpose and Scope

Hilti has developed an anchor known as the Hilti Kwik Bolt TZ (KB-TZ) Expansion Anchor System specifically for use in the tension zone of concrete and under static and seismic loadings. The purpose of this document is to evaluate the qualification testing performed on the KB-TZ Anchor System and determine whether it is in compliance with the requirements of ACI 355.2-01 and ACI 349-01 as recognized by the United States Nuclear Regulatory Commission in USNRC Regulatory Guide 1.199.

A design guide for use of the KB-TZ anchor system under ACI 349-01 and USNRC Directive 1.199 is given in **Appendix A** (supplied by Hilti, Inc.). All data in **Appendix A** meets the requirements of these two documents.

## 2. Qualification Testing Program

**2.1** Testing was ordered by Hilti in 2004 and conducted under the guidance of Bruno Mesureur at the Centre Scientific et Technique du Batiment, (CSTB) Marne-la-Vallee, France. Testing was performed according to AC193 (June 2004).

**2.2** AC193 issued by the ICC Evaluation Service references ACI 355.2 as the base document for the testing and evaluation protocol, adding additional ICC-ES specific requirements as well as modifications to specific testing and evaluation requirements. Those differences and the resulting anchor qualification and KB-TZ design data will be the focus of this document.

**2.3** For anchors to be used in facilities under the purview of the USNRC, USNRC requirements must be met. Those requirements are summarized in Regulatory Guide 1.199. In that guide, ACI 349-01 Appendix B *Anchoring to Concrete* contains the basic design requirements for anchoring, and ACI 355.2 is an acceptable testing guide for mechanical anchors.

**2.4** All submitted testing of the KB-TZ expansion anchor system was performed in a satisfactory manner and submitted to ICC-ES for their review. After considerable review, an evaluation service report (ESR) was issued, ESR 1917, which recognized compliance with AC193. The ESR specified the appropriate design data and parameters for use with ACI 318-02, Appendix D.

**2.5** Because of differences in evaluation requirements between ACI 355.2-01 and actual testing performed under AC193, this report has been prepared to explain and comment on those differences.

### **3. Testing Differences among ICC-ES AC193, ACI 355.2-01, and ACI 349-01 Requirements and Resolution of those Differences**

#### **3.1 Testing to be performed or witnessed by an accredited laboratory.**

ACI 355.2-01 in Section 12.1 states that,

“The testing and evaluation of anchors under ACI 355.2-01 shall be performed or witnessed by an independent testing and evaluation agency listed by a recognized accreditation service conforming to the requirements of ISO Guides 25 and 58. In addition to these standards, listing of the Testing and Evaluation Agency shall be predicated on the documented experience in the testing and evaluation of anchors according to ASTM E 488 including demonstrated competence to perform the tests described in ACI 355.2-01.”

ACI 349-01 states in Section B3.3 that,

“Post-installed structural anchors shall be tested before use to verify that they are capable of sustaining their design strength in cracked concrete under seismic loads. These verification tests shall be conducted by an independent testing agency and shall be certified by a professional engineer with full description and details of the testing programs, procedures, results, and conclusions.”

Test data obtained for the KB-TZ evaluation according to Annex 1, Section 5.3, of AC193, was required to be performed in a laboratory accredited under the requirements of ISO/IEC 17025. Further, a listing, by an accredited listing agency, of the testing and evaluation laboratory was required to be based on the documented experience in the testing and evaluation of anchors according to ASTM E 488.

**Resolution:** Testing was performed primarily by the Centre Scientific et Technique du Batiment, (CSTB) Marne-la-Vallee, France. Other laboratories were also used as given in the following list, taken from the evaluation report prepared by CSTB. All of the listed laboratories were accredited by the International Laboratory Accreditation Cooperation (ILAC) under ISO/IEC 17025. IAS, the laboratory and testing accrediting body of the ICC, is also a member of ILAC. The European accreditation of these testing laboratories was

accepted as being competent in the testing of anchor systems. CSTB was accredited in direct audits by IAS.

**Table 1—Testing laboratories used for KB-TZ testing**

1. CSTB: Centre Scientific et Technique du Batiment, Marne-la-Vallee, France (accredited by COFRAC (full ILAC-member))
2. BAUTESCHNICHE VERSUCHSANSTALT, Negrellistrasse 50, A-6830 Rankweil, Austria
3. BAUTEST Gesellschaft für Forschung und Materialprüfung im Bauwesen GmbH, Augsburg, Germany (accredited by DAP (full ILAC-member))
4. IFBT: Institut für Fassaden- und Befestigungstechnik GmbH Leipzig, Germany (DIBt-accredited)

### 3.2 Testing under the direction of a licensed professional engineer.

ACI 355.2-01 states in Section 12.2 that, "The testing shall be witnessed and evaluated by a registered engineer employed or retained by the independent testing and evaluation agency."

**Resolution:** Testing was overseen by and the Evaluation report submittal prepared by Bruno Mesureur of the CSTB. Mr. Mesureur is not a registered engineer because there is no formal engineering registration system in Europe. Note that in Europe, licensing of structural engineers is accomplished through accredited educational institutions. Mr. Mesureur is accredited for performing structural engineering. He also has been involved in the creation of the testing protocol for mechanical anchors in Europe under the EOTA working group on "Fastenings" concerned with the drafting of the ETAG's (European Technical Approval Guidelines).

Mr. Meseureur's list of technical credentials associated with anchoring and fastening technology give him the background for testing and evaluating anchor systems.

### 3.3 Method used to calculate the effectiveness factor, $k$ .

Both ACI 355.2-01 and ACI 349-01 require that the  $k$ -factor (effectiveness factor, whose value depends on the type of anchor) reported for the anchors be calculated from the 5% fractile of the test data. ICC-ES AC193 allows the mean values to be used as an alternative to the 5% fractile, and ICC-ES ESR 1917 reports the  $k$ -factor calculated from the mean test data.

**Resolution:** The original test data used in developing ESR 1917 was evaluated using both the 5% fractile and mean values. There is no difference between the  $k$ -factors using the 5% fractile of the test data and the mean test data. The published values in ESR 1917 were based on the mean values. The values used in **Appendix A—Design information for the Hilti Kwik Bolt TZ in Accordance with ACI 349-01 Appendix B** are based on 5% fractile calculations.

<b>Table 2—Comparison of effectiveness factors, <math>k</math> (in.-lb units)</b>		
Based on both mean and 5% fractile calculation	Uncracked concrete	Cracked concrete
All diameters -	24	17

### 3.4 Calculation of concrete compressive strengths.

Since the testing was performed in CSTB test laboratories, the concrete compressive strengths were determined according to European standards using the 150 mm cube strength rather than the 150 mm x 300 mm cylinder strengths used typically in the United States.

**Resolution:** In the evaluation performed for ESR 1917, these cube strengths were converted from SI units to in.-lb units using standard conversion equations that have been universally accepted in both the European and United States concrete industry. They are as follows.

$$f_{c,cyl} = f_{c,cube\ 150} / 1.25 \quad \text{for low strength concrete } f_{c,cyl} < 50 \text{ N/mm}^2$$

$$f_{c,cyl} = f_{c,cube\ 150} / 1.05 \quad \text{for high strength concrete } f_{c,cyl} \geq 50 \text{ N/mm}^2$$

### 3.5 Question on measurement of ductility of the KB-TZ anchor steel.

ACI 355.2-01 does not contain criteria for establishing the ductility of mechanical anchor steel. ACI 318-02 (Section D.1 Definitions) define it as, “**ductile steel element**—An element with a tensile test elongation of at least 14 percent and reduction in area of at least 30 percent. A steel element meeting the requirements of ASTM A 307 shall be considered ductile.”

**Resolution:** AC193 has incorporated a method for determination of anchor steel element ductility.

**4.3.9 Classification of Anchor Steel as Ductile or Brittle**—Elongation and reduction of area shall be determined according to a recognized standard and reported on the data sheet (Chapter 11). If the elongation is at least 14 percent and the reduction of area is at least 30 percent, the anchor shall be considered to meet the ductile steel requirements. If the ductility and reduction of area cannot be determined, the anchor shall be reported as brittle in the report.

While ACI 355.2-01 does not specify how ductility shall be determined or performed, testing of steel elements in the USA typically uses ASTM F 606. As explained by Eligehausen and Asmus in the submittal to ICC-ES, the elongation is measured over a gage length of  $4d$ . In Europe, where the ductility testing was performed on the KB-TZ anchor, the elongation is measured according to EN 10002 and ISO 898, using a gage length of  $5d$ . The elongation is measured after rupture of the steel, and is referred to as rupture elongation. Since the measured elongation contains a small plastic deformation due to contraction of the steel after passing the peak load, the contraction is limited to a small length. Under ISO 898, a minimum 12% elongation is required with a gage length of  $5d$ , which related to a 14% elongation under ASTM F 606.

Elongation testing performed in accordance with EN 10002 and ISO 898 was submitted, reviewed, and accepted by ICC-ES. The data demonstrated the actual rupture elongation was even greater than required as a ductile steel element.

Therefore the elongation requirement is met. Similarly, the measured reduction of area was greater than 30%. In conclusion, the KB-TZ anchor steel meets the AC193 requirement of “ductility”.



## 4. Conclusions and Recommendations

**4.1** The areas where ACI 355.2-01 and ACI 349-01 differ from AC193 are discussed above. Evidence is provided demonstrating that, while the language of the standards varies, the actual testing and evaluation never-the-less met their intent and requirements. The remainder of ACI 355.2-01 and ACI 349-01 does not contain any other requirements that are functionally different from AC193. Therefore after review of all pertinent data and evaluations, it is my opinion that the testing performed on the Hilti KB-TZ ANCHOR system meets the intent and requirements of ACI 355.2-01 and ACI 349-01.

The evaluations performed and the data as presented in **Design information for the Hilti Kwik Bolt TZ Expansion Anchor in Accordance with ACI 349-01 Appendix B** attached as Appendix A to this report are accurate and comply with the intent and requirements of ACI 355.2-01, ACI 349-01, and USNRC Regulatory Guide 1.199.



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November 4, 2011  
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## 5. References

1. ACI 349-01 *Code Requirements for Nuclear Safety Related Concrete Structures*; Appendix B, Anchoring to Concrete; American Concrete Institute, Farmington Hills, MI.
2. ACI 355.2-01 *Evaluating the Performance of Post-Installed Mechanical Anchors in Concrete*; American Concrete Institute; Farmington Hills, MI.
3. ASTM E 488-96 (Reapproved 2003), *Standard Test Methods for Anchors in Concrete and Masonry Elements*; American Society for Testing and Materials; West Conshohocken, PA
4. ASTM F 606-02, *Standard Test Methods for Determining the Mechanical Properties of Externally and Internally Threaded Fasteners, Washers, Direct Tension Indicators, and Rivets*; American Society for Testing and Materials; West Conshohocken, PA.
5. ICC-Evaluation Service Inc., Whittier, CA; *Acceptance Criteria for Mechanical Anchors in Concrete Elements (AC193)*; June, 2004.
6. EN 10002-01:2001; *Tensile testing of metallic materials*; International Standards Organization; September 2001.
7. ISO/IEC 17025; *General Requirements for the Competence of Testing and Calibration Laboratories*; International Standards Organization; December 1999.
8. ISO 898, *Mechanical Properties of Fasteners made of Carbon Steel and Alloy Steel – Part 1: Bolts, Screws and Studs with Specified Property Classes – Coarse Thread and Fine Pitch Thread*; International Standards Organization; August 1999;
9. ICC-ES Evaluation Service Report ESR 1917, *Hilti Kwik Bolt TZ Carbon and Stainless Steel Expansion Anchors in Cracked and Uncracked Concrete*, issued May 2011.
10. U.S. Nuclear Regulatory Commission, Washington, DC: *Regulatory Guide 1.199, Anchoring Components and Structural Supports in Concrete*; November 2003.
11. Hilti, Inc., Tulsa, OK: *Design Information for the Hilti Kwik Bolt TZ Expansion Anchor in Accordance with ACI 349-01 Appendix B*, June 2011.

## Appendix A

### Design information for the Hilti Kwik Bolt TZ Expansion Anchor in Accordance with ACI 349-01 Appendix B.

#### 1.0 SCOPE

This guide is intended to provide guidance for the design of anchorages using the Hilti Kwik Bolt TZ (KB-TZ) in accordance with ACI 349-01 Appendix B. Note that this design varies from current general industry practice following ACI 318 Appendix D. It is the responsibility of the engineer of record to verify the accuracy and suitability of all design calculations, methodologies, capacities and code compliance. Information contained in this document was current as of August 30, 2010, and subject to change. Updates and changes may be made based on later testing. If verification is needed that the data is still current, please contact Hilti Technical Services at 1-877-749-6337.

#### 2.0 USES

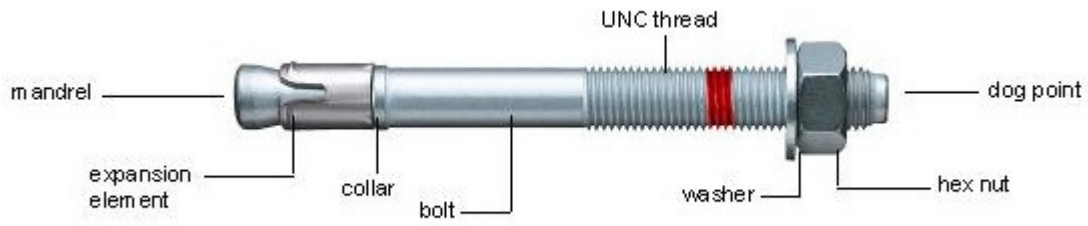
The Hilti Kwik Bolt TZ expansion anchor is used to resist static, wind, and seismic tension and shear loads in cracked and uncracked normal-weight concrete having a specified compressive strength  $2,500 \text{ psi} \leq f'_c \leq 8,500 \text{ psi}$  ( $17.2 \text{ MPa} \leq f'_c \leq 58.6 \text{ MPa}$ ). The values of  $f'_c$  used for calculations in this guide shall not exceed 8,000 psi (55.2 MPa).

#### 3.0 INSTALLATION

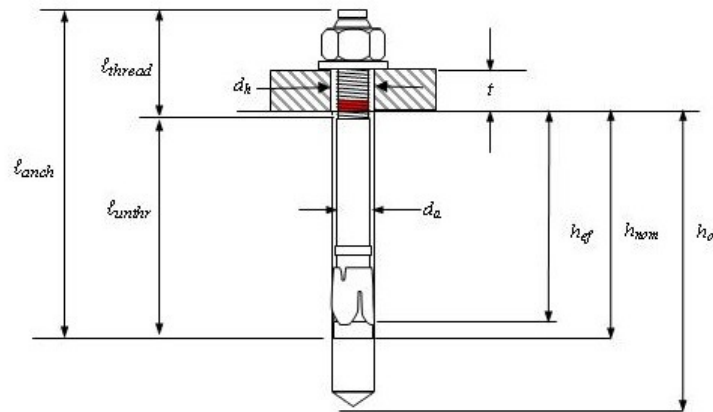
Installation shall be in accordance with Hilti's printed installation instructions as included in the anchor packaging.

#### 4.0 DESIGN

The design shall be in accordance with this document and ACI 349-01 Appendix B. See Figure 4 for a worked example for static tension loading.



**FIGURE 1—KB-TZ**



**FIGURE 2—CORRECT INSTALLATION OF KB-TZ**

TABLE 1—KB-TZ DESIGN INFORMATION

DESIGN INFORMATION	Symbol	Units	Nominal anchor diameter											
			3/8		1/2		5/8		3/4					
Anchor O.D.	$d_o$	in. (mm)	0.375 (9.5)		0.5 (12.7)		0.625 (15.9)		0.75 (19.1)					
Effective min. embedment	$h_{ef}$	in. (mm)	2 (51)		2 (51)		3-1/4 (83)		3-1/8 (79)	4 (102)		3-3/4 (95)		4-3/4 (121)
Min. member thickness	$h_{min}$	in. (mm)	4 (102)	5 (127)	4 (102)	6 (152)	6 (152)	8 (203)	5 (127)	6 (152)	8 (203)	6 (152)	8 (203)	8 (203)
Critical edge distance	$c_{cr}$	in. (mm)	4-3/8 (111)	4 (102)	5-1/2 (140)	4-1/2 (114)	7-1/2 (191)	6 (152)	6-1/2 (165)	8-3/4 (222)	6-3/4 (171)	10 (254)	8 (203)	9 (229)
Min. edge distance	$c_{min}$	in. (mm)	2-1/2 (64)		2-3/4 (70)		2-3/8 (60)		3-5/8 (92)	3-1/4 (83)		4-3/4 (121)		4-1/8 (105)
	for $s \geq$	in. (mm)	5 (127)		5-3/4 (146)		5-3/4 (146)		6-1/8 (156)	5-7/8 (149)		10-1/2 (267)		8-7/8 (225)
Min. anchor spacing	$s_{min}$	in. (mm)	2-1/2 (64)		2-3/4 (70)		2-3/8 (60)		3-1/2 (89)	3 (76)		5 (127)		4 (102)
	for $c \geq$	in. (mm)	3-5/8 (92)		4-1/8 (105)		3-1/2 (89)		4-3/4 (121)	4-1/4 (108)		9-1/2 (241)		7-3/4 (197)
Min. hole depth in concrete	$h_o$	in. (mm)	2-5/8 (67)		2-5/8 (67)		4 (102)		3-7/8 (98)	4-3/4 (121)		4-1/2 (117)		5-3/4 (146)
Min. specified yield strength	$f_y$	lb/in <sup>2</sup> (N/mm <sup>2</sup> )	100,000 (690)		84,800 (585)		84,800 (585)		84,800 (585)		84,800 (585)		84,800 (585)	
Min. specified ult. strength	$f_u$	lb/in <sup>2</sup> (N/mm <sup>2</sup> )	115,000 (862)		106,000 (731)		106,000 (731)		106,000 (731)		106,000 (731)		106,000 (731)	
Effective tensile stress area	$A_{se}$	in <sup>2</sup> (mm <sup>2</sup> )	0.052 (33.6)		0.101 (65.0)		0.162 (104.6)		0.162 (104.6)		0.237 (152.8)		0.237 (152.8)	
Steel strength in tension	$N_s$	lb (kN)	6,500 (28.9)		10,705 (47.6)		17,170 (76.4)		17,170 (76.4)		25,120 (111.8)		25,120 (111.8)	
Steel strength in shear	$V_s$	lb (kN)	3,595 (16.0)		5,495 (24.4)		8,090 (36.0)		8,090 (36.0)		13,675 (60.8)		13,675 (60.8)	
Steel strength in shear, seismic <sup>5</sup>	$V_{seis}$	lb (kN)	2,255 (10.0)		5,495 (24.4)		7,600 (33.8)		7,600 (33.8)		11,745 (52.2)		11,745 (52.2)	
Pullout strength uncracked concrete <sup>4</sup>	$N_{p,uncr}$	lb (kN)	2,515 (11.2)		-		5,515 (24.5)		-	9,145 (40.7)		8,280 (36.8)		10,680 (47.5)
Pullout strength cracked concrete <sup>4</sup>	$N_{p,cr}$	lb (kN)	2,270 (10.1)		-		4,915 (21.9)		-	-		-		-
Effectiveness factor $k_{uncr}$ uncracked concrete			24											
Effectiveness factor $k_{cr}$ cracked concrete <sup>2</sup>			17											
$\psi_3 = k_{uncr}/k_{cr}^3$			1.41											
Strength reduction factor $\phi$ for tension, steel failure modes <sup>1</sup>			0.80											
Strength reduction factor $\phi$ for shear, steel failure modes <sup>1</sup>			0.75											
Strength reduction factor $\phi$ for concrete breakout, side-face blowout, pullout, or pryout failure modes <sup>1</sup>			0.75											

For SI: 1 inch = 25.4 mm, 1 lbf = 4.45 N, 1 psi = 0.006895 MPa For pound-inch units: 1 mm = 0.03937 inches.

<sup>1</sup> ACI 349-01, Appendix B, section B.4.4. For use with the load combinations of ACI 349-01, section 9.2.

<sup>2</sup> ACI 349-01 Appendix B, section B.5.2.2 and B.5.2.8

<sup>3</sup> ACI 349-01 Appendix B, section B.5.2.6

<sup>4</sup> In lieu of ACI 349-01 Appendix B, section B.5.3.1 for pullout failure,  $N_{p,cr}$  shall be used to calculate the pullout strength for cracked concrete and  $N_{p,uncr}$  shall be used to calculate the pullout strength for uncracked concrete. The modification factor  $\psi_4$  shall then be taken as 1.0.

<sup>5</sup>  $V_{seis}$  shall be used in lieu of  $V_s$  for load combinations that include earthquake loads.

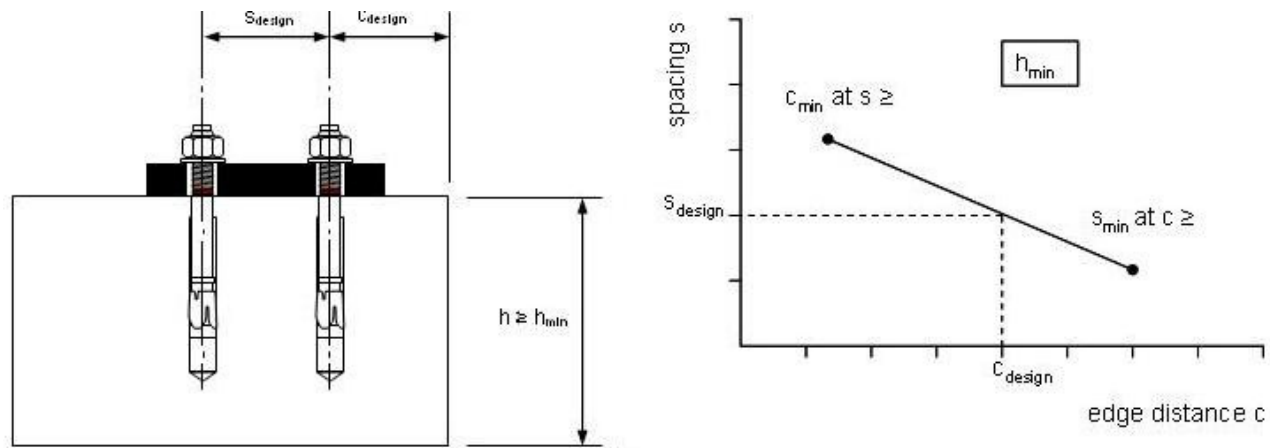


FIGURE 3—KB-TZ EXAMPLE OF ALLOWABLE INTERPOLATION OF MINIMUM EDGE DISTANCE AND MINIMUM SPACING

FIGURE 4—KB-TZ EXAMPLE CALCULATION

<p><b>ven:</b>                  (2) 1/2 –inch carbon steel KB-TZ anchors under static tension load as shown.  <math>h_{ef} = 3.25</math> in.                  Slab on grade with <math>f'_c = 3,000</math> psi.                  Assume cracked normalweight concrete.                  Calculate the design strength in tension for this configuration.</p>			
<p><b>Calculation per ACI 349-01 Appendix B and this document.</b></p>		<p>ACI 349-01</p>	<p>Guide Ref.</p>
<p><b>Step 1.</b> Calculate steel strength of anchor in tension  <math>N_s = n A_{se} f_{ut} = 2 \times 0.101 \times 106,000 = 21,412</math> lb</p>			
<p><b>Step 2.</b> Calculate steel capacity  <math>\phi N_s = 0.8 \times 2 \times 21,412</math> lb = 17,128 lb</p>			
<p><b>Step 3.</b> Calculate concrete breakout strength of anchor in tension <math>N_{cbg} = \frac{A_N}{A_{No}} \psi_1 \psi_2 \psi_3 N_b</math></p>			
<p><b>Step 4.</b> Verify minimum spacing and edge distance:                   Table 1 <math>h_{min} = 6</math> in. okay  <math>c_{actual} = 4</math> in.  <math>s_{actual} = 6</math> in.                   The plotted coordinates are to the right of the line. okay</p>		<p>B.8</p>	<p>Table 1</p>
<p><b>Step 5.</b> Calculate <math>A_{No}</math> and <math>A_N</math> for the anchorage:  <math>A_{No} = 9h_{ef}^2 = 9(3.25 \text{ in.})^2 = 95.06 \text{ in.}^2</math>  <math>A_N = (1.5h_{ef} + 4 \text{ in.})(1.5h_{ef}^2 + 6 \text{ in.} + 1.5h_{ef})</math>  <math>= (4.875 \text{ in.} + 4 \text{ in.})(4.875 \text{ in.} + 6 \text{ in.} + 4.875 \text{ in.})</math>  <math>= 139.78 \text{ in.}^2</math></p>			

<b>Step 6.</b> Calculate $N_b = k_{cr} \sqrt{f'_c} h_{ef}^{1.5} = 17 \sqrt{3,000 \text{ psi}} 3.25 \text{ in.}^{1.5} = 5,456 \text{ lb}$	B.5.2.2	Table 1
<b>Step 7.</b> Modification factor for eccentricity $\rightarrow$ no eccentricity $e'_N = 0 \therefore \Psi_1 = 1.0$	B.5.2.4	-
<b>Step 8.</b> Modification factor for edge $1.5 h_{ef} = 4.875 \text{ in.} > 4.00 \text{ in.} \Rightarrow \psi_2$ must be calculated $\psi_2 = 0.7 + 0.3 \left( \frac{4.00 \text{ in.}}{4.875 \text{ in.}} \right) = 0.95$	B.5.2.5	Table 1
<b>Step 9.</b> Modification factor for cracked concrete $\Psi_3 = 1.0$	B.5.2.2 B.5.2.6 B.5.2.8	Table 1
<b>Step 10.</b> Calculate concrete breakout strength. $N_{cbg} = \left( \frac{139.78 \text{ in.}^2}{95.06 \text{ in.}^2} \right) (1.0)(0.95)(1.0)(5,456 \text{ lb}) = 7,622 \text{ lb}$	B.5.2.1	-
<b>Step 11.</b> Calculate pullout strength $N_{p,cr} = 4,915 \text{ lb} \Rightarrow (2)(4,915 \text{ lb}) = 9,830 \text{ lb}$	B.5.3.2	Table 1
<b>Step 12.</b> $\phi N_{cbg} = (0.75)(7,622 \text{ lb}) = 5,717 \text{ lb} < \phi N_s \Rightarrow$ concrete breakout strength controls	B.4.4 c	Table 1
<b>Step 13.</b> Ductility check according to B.3.6.1 For tension: $0.85 \min[N_{cbg}; N_{p,cr}] \geq A_{se} f_{ut}$ $= 0.85 (7,622) < 21,412 \text{ lb} \therefore$ ductility not met B.3.6.3 requires an additional reduction factor of 0.6 for non-ductile anchors. $0.6 \phi N_{cbg} = (0.6)(5,717 \text{ lb}) = 3,430 \text{ lb}$	B.3.6.1  B.3.6.3/ B.4.1	Table 1