Report on Applicability of the Hilti HDA Undercut 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 12-01

Prepared for
Hilti, Inc.
Tulsa Oklahoma

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May 23, 2012

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1. Purpose and Scope

Hilti has developed an undercut anchor known as the HDA Heavy Duty Undercut Anchor System. The purpose of this document is to evaluate the qualification testing performed on the Hilti HDA Heavy Duty 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 HDA 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 on May 11, 2002 and conducted under the guidance of Prof. Dr.-ing Rolf Eligehausen of the University of Stuttgart, Germany in 2002 and 2003 at the Institut Für Werkstoffe Im Bauwesen and other testing laboratories. Testing was performed according to AC193.

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 HDA 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 HDA 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 1546, 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 12.1states 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 HDA 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 Institut Für Werkstoffe Im Bauwesen. Other laboratories were also used as given in the following list, taken from the evaluation report prepared by Prof. Eligehausen. 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. IWB and CSTB were accredited in direct audits by IAS.

Table 1. Testing laboratories used for HDA testing

1. CSTB: Centre Scientific et Technique du Batiment, Marne-la-Vallee, France (accredited by COFRAC (full ILAC-member)
2. IWB: Institut für Werkstoffe im Bauwesen der Universität Stuttgart, Germany (accredited by ICC ES, IAS, and DAR (full ILAC-member))
3. HTL: Bautechnische Versushsanstalt an der HTL Rankweil, Austria (accredited by BMWA (full ILAC-member))
4. F: Forschungs- und Materialprüfungsanstalt Baden Württemberg Otto-Graf-Institut, Stuttgart, Germany (DIBt-accredited)
5. L: Material Research and Testing Institute for Construction, Liepzig, Germany (DIBt-accredited)
6. D: Institut für Bauforschung, Dortmund, Germany

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 Prof. Dr.-Ing. Rolf Eligehausen of the University of Stuttgart Institute for Building Materials. (He is now retired.). Prof. Eligehausen 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. Prof. Eligehausen is accredited for performing structural engineering. His experience in the technology of fastening to concrete is significant.

Prof. Eligehausen has been conducting evaluation and approval of anchors in Europe for more than 25 years, initially under DIBt (German) rules, and later under the EOTA (European Organisation for Technical Approvals (http://www.eota.be) guidelines. He participated in the development of the criteria for qualification of anchor systems both in Europe and the United States. As the author or co-author of over 230 papers and publications in Europe and the U.S. on the subject of bond and anchorage and as a Fellow of the American Concrete Institute, Prof. Eligehausen has established a reputation on both sides of the Atlantic as the pre-eminent expert in the world on anchorage to concrete. In addition, Prof. Eligehausen conducts his own structural engineering practice as founder and principal of IEA (Ingenieurbüro Eligehausen und Asmus http://www.i-ea.de).

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 1546 reports the *k*-factor calculated from the mean test data.

Resolution: The original test data used in developing ESR 1546 was evaluated using both the 5% fractile and mean values. There is no difference between the *k-factor*s using the 5% fractile of the test data and the mean test data. The published values in ESR 1546 were based on the mean values. The values used in **Appendix A—Design information for the Hilti Undercut Anchor HDA in Accordance with ACI 349-01 Appendix B** were based on 5% fractile calculations. They are the same.

Table 2—Comparison of effectiveness factors, *k*.

	Uncracked concrete	Cracked concrete
Based on 5% fractile calculation	30	24
Based on mean test data calculation	—	24

3.4 Calculation of concrete compressive strengths.

Since the testing was performed in a German test laboratory, 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 1546, 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.

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

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

3.5 Question on measurement of ductility of the HDA 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 4*d*. In Europe, where the ductility testing was performed on the HDA anchor, the elongation is measured according to EN 10002 and ISO 898, using a gage length of 5*d*. 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 if 5*d*, 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.

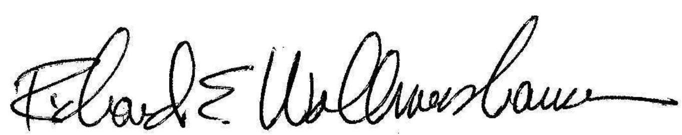
Therefore the elongation requirement is met. Similarly, the measured reduction of area was greater than 30%. In conclusion, the HDA anchor steel meets the AC193 requirement of "ductility".

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 HDA 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 Undercut Anchor HDA in Accordance with ACI 349-01 Appendix B** attached to this report as Appendix A are accurate and comply with the intent and requirements of ACI 355.2-01, ACI 349-01, and USNRC Regulatory Guide 1.199.

Note: This report was originally released as WC 11-01 on June 30, 2011. This release contains only revisions to Tables 1, 2, and 3 of Appendix A. The minimum thicknesses of the base plates for the M10x100 HDA anchors were increased to 15 mm. All other information in the report remains the same.



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May 25, 2012
Tulsa, Oklahoma

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); January, 2003.

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 andAlloy 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 1546, *Hilti HDA Carbon Steel and Stainless Steel Undercut Anchors for Cracked and Uncracked Concrete*, issued August 2004. Latest report issued March 2012.

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 Undercut Anchor HDA in Accordance with ACI 349-01 Appendix B,* June 2011.

Appendix A

(Data supplied by Hilti, Inc, Tulsa, Oklahoma)

Design information for the Hilti Undercut Anchor HDA in Accordance with ACI 349-01 Appendix B.

1.0 SCOPE

This document is intended to provide guidance on the design of anchorages with Hilti Undercut Anchors HDA in accordance with ACI 349-01 Appendix B. Note 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 May 23, 2012, and is subject to change. Updates and changes may be made based on subsequent 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 HDA Undercut 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 psi ≤ f'_c ≤ 8,500 psi (17.2 MPa ≤ f'_c ≤ 58.6 MPa). The values of f'_c used for calculations in this guide shall not exceed 8000 psi (55.2 MPa).

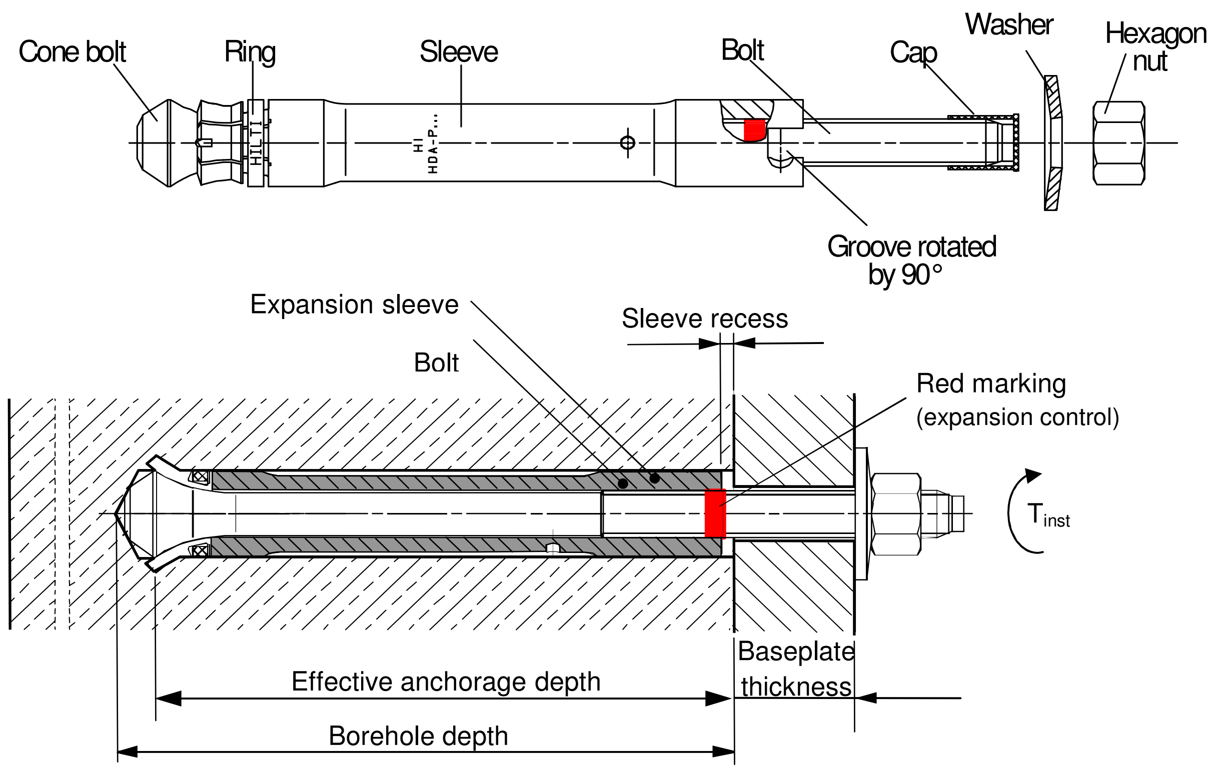
3.0 INSTALLATION

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 3 for a worked example for static tension loading.

Figure 1 - Pre-setting anchor HDA-P and HDA-PR (Pre-setting)



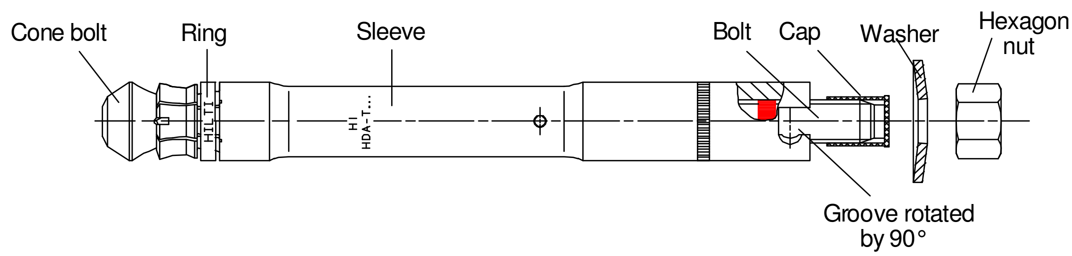


Figure 2—Through-fastening anchor HDA-T and HDA-TR (Through-Setting)

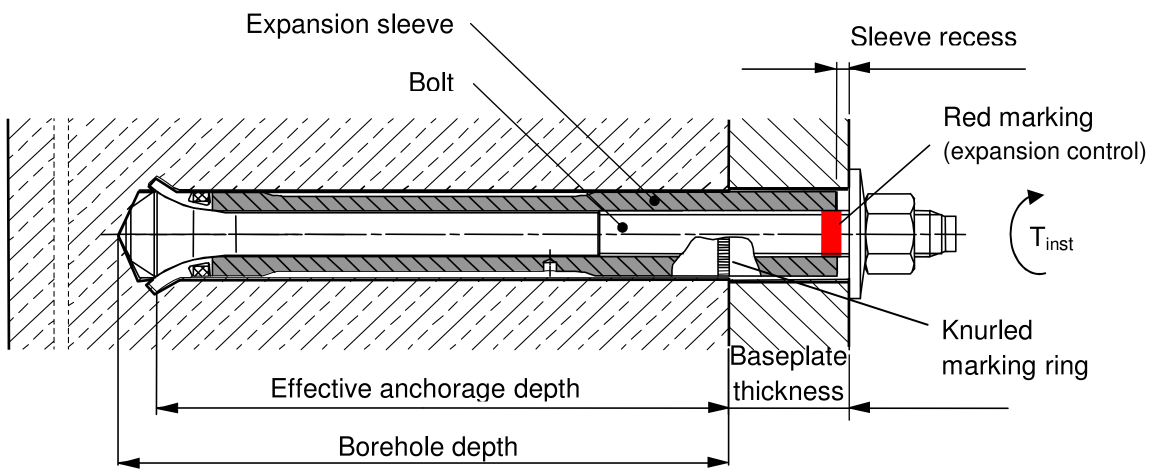


Table 1—HDA Design information

Design parameter	Symbol	Units	Nominal anchor diameter						
			M10		M12		M16		M20
			HDA	HDA-R	HDA	HDA-R	HDA	HDA-R	HDA
Anchor diameter	d_0	mm (in.)	19 (0.75)		21 (0.83)		29 (1.14)		35 (1.38)
Effective min. embedment depth[1,9]	$h_{ef,min}$	mm (in.)	100 (3.94)		125 (4.92)		190 (7.48)		250 (9.84)
Minimum edge distance[7]	c_{min}	mm (in.)	80 (3-1/8)		100 (4)		150 (5-7/8)		200 (7-7/8)
Minimum anchor spacing	s_{min}	mm (in.)	100 (4)		125 (5)		190 (7-1/2)		250 (9-7/8)
Minimum member thickness	h_{min}	-	See Tables 4a and 4b						
Strength reduction factor for tension, steel failure modes[2]	ϕ	-	0.80						
Strength reduction factor for shear, steel failure modes[2]	ϕ	-	0.75						
Strength reduction factor for concrete breakout, side-face blowout, pullout or pryout strength[2]	ϕ	-	0.75						
Yield strength of anchor steel	f_y	lb/in[2]	92,800						
Ultimate strength of anchor steel	f_{ut}	lb/in[2]	116,000						
Tensile stress area	A_{se}	in[2]	0.090		0.131		0.243		0.380
Steel strength in tension	N_s	lb	10,431		15,152		28,236		44,063
Effectiveness factor cracked concrete[3]	k	-	24	24	24	24	24	24	24
Modification factor for uncracked concrete[4]	Ψ_3	-	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Pullout strength cracked concrete, static and seismic[5]	$N_{p,cr}$	lb	8,992	8,992	11,240	11,240	22,481	22,481	33,721
Steel strength in shear, static HDA-P/PR[6]	V_s	lb	5,013	6,070	7,284	8,992	13,556	16,861	20,772
Steel strength in shear, seismic[6] HDA-P/PR	$V_{s,seismic}$	lb	4,496	5,620	6,519	8,093	12,140	15,062	18,659
Axial stiffness in service load range in cracked / uncracked concrete[8]	β	10^3 lb/in.	80 / 100						

[1]Actual h_{ef} for HDA-T is given by $h_{ef,min} + (t_{fix,max} - t_{fix})$ where $t_{fix,max}$ is given in Table 4b and t_{fix} is the thickness of the part(s) being fastened.

[2]See ACI 349-01, Appendix B, section B.4.4. For use with the load combinations of ACI 349-01, section 9.2.

[3]See ACI 349-01 Appendix B, section B.5.2.2 and B.5.2.8. The k factor for the HDA Undercut anchor is based on testing and assessment in accordance with ACI 355.2-01.

[4]See ACI 349-01 Appendix B, section B.5.2.6 and B.5.2.8. The value Ψ_3 is calculated to k_{uncr}/k_{cr} = 30/24 = 1.25. The k factors for the HDA Undercut anchor are based on testing and assessment in accordance with ACI 355.2-01.

[5]The pullout strength of the anchor in cracked concrete is governed by anchor displacement under conditions with crack width cycling. In uncracked concrete, pullout does not govern.

[6]For HDA-T see Table 2.

[7]Splitting failure under external load does not govern the resistance of the HDA. Therefore, no values for the critical edge distance c_{cr} are provided since this calculation is not required for design.

[8]Minimum axial stiffness values, maximum values may be 3 times larger (e.g. due to high strength concrete)

[9]To calculate the basic concrete breakout strength V_b, ℓ equals h_{ef}. In no cases shall ℓ exceed $8d_o$. See ACI 349-01 Appendix B, section B.0

Table 2—Design information - Steel strength in shear, HDA-T and HDA-TR

Anchor Designation		Thickness of base plate(s) t_{fix}		Steel Strength in Shear, Static V_s	Steel Strength in Shear, Seismic $V_{s,seismic}$
		mm	in.	lb	lb
Carbon Steel Anchors	HDA-T 20-M10x100	$15 \le t_{fix} < 20$	$^5/_8 \le t_{fix} < {}^{13}/_{16}$	13,938	12,589
	HDA-T 22-M12x125	$15 \le t_{fix} \le 20$	$5/8 \le t_{fix} \le 13/16$	16,636	15,062
		$20 \le t_{fix} \le 50$	$13/16 \le t_{fix} \le 2$	18,659	16,636
	HDA-T 30-M16x190	$20 \le t_{fix} \le 25$	$13/16 \le t_{fix} \le 1$	30,574	27,427
		$25 \le t_{fix} \le 30$	$1 \le t_{fix} \le 1\text{-}3/16$	34,621	31,248
		$30 \le t_{fix} \le 35$	$1\text{-}3/16 \le t_{fix} \le 1\text{-}3/8$	38,218	34,396
		$35 \le t_{fix} \le 60$	$1\text{-}3/8 \le t_{fix} \le 2\text{-}3/8$	41,365	37,093
	HDA-T 37-M20x250	$25 \le t_{fix} \le 40$	$1 \le t_{fix} \le 1\text{-}9/16$	45,187	40,690
		$40 \le t_{fix} \le 55$	$1\text{-}9/16 \le t_{fix} \le 2\text{-}1/8$	50,807	45,636
		$55 \le t_{fix} \le 100$	$2\text{-}1/8 \le t_{fix} \le 4$	54,629	49,233
Stainless Steel Anchors	HDA-TR 20-M10x100	$15 \le t_{fix} < 20$	$^5/_8 \le t_{fix} < {}^{13}/_{16}$	15,512	13,938
	HDA-TR 22-M12x125	$15 \le t_{fix} \le 20$	$5/8 \le t_{fix} \le 13/16$	20,233	17,985
		$20 \le t_{fix} \le 50$	$13/16 \le t_{fix} \le 2$	22,256	20,008
	HDA-TR 30-M16x190	$20 \le t_{fix} \le 25$	$13/16 \le t_{fix} \le 1$	35,745	32,148
		$25 \le t_{fix} \le 30$	$1 \le t_{fix} \le 1\text{-}3/16$	37,768	33,946
		$30 \le t_{fix} \le 35$	$1\text{-}3/16 \le t_{fix} \le 1\text{-}3/8$	39,566	35,520
		$35 \le t_{fix} \le 60$	$1\text{-}3/8 \le t_{fix} \le 2\text{-}3/8$	40,915	36,869

For pound-inch units: 1 mm = 0.03937 inch, 1 lb_f = 4.45 N.

For the M10x100 HDA anchors, base plate thicknesses < 15 mm were deleted from previous versions of the design guide. (5/23/2012)

Table 3—HDA Hole in base plate(s) and minimum thickness of base plate(s)

HDA M10 to M20 and HDA-R M10 to M16			M10		M12		M16		M20	
			P	T	P	T	P	T	P	T
Hole diameter in base plate(s)	d_h	mm	12	21	14	23	18	32	22	40
		(in.)	(0.47)	(0.83)	(0.55)	(0.91)	(0.71)	(1.26)	(0.87)	(1.57)
Min. thickness of base plate(s)	$t_{fix,min}$	mm	0	15[1]	0	15	0	20	0	25
		(in.)	0	(0.59)	0	(0.59)	0	(0.79)	0	(0.98)

For in-lb units: 1mm = 0.03937 inches

[1] Minimum thickness increased to 15 mm (5/23/2012)

Table 4a—Maximum thickness of base plate(s) and minimum thickness of concrete, HDA-P and HDA-PR

Anchor type			HDA-P M10 HDA-PR M10	HDA-P M12 HDA-PR M12		HDA-P M16 HDA-PR M16		HDA-P M20	
Maximum thickness of base plate(s)	$t_{fix,max}$	mm	20	30	50	40	60	50	100
		in.	0.79	1.18	1.97	1.57	2.36	1.97	3.94
Minimum thickness of concrete member	h_{min}	mm	180	200		270		350	
		in.	7.1	7.9		10.6		13.8	

For inch units: 1 mm = 0.03937 inches

Table 4b—Maximum thickness of base plate(s) and minimum thickness of concrete, HDA-T and HDA-TR

Anchor type			HDA-T M10 HDA-TR M10	HDA-T M12 HDA-TR M12		HDA-T M16 HDA-TR M16		HDA-T M20	
Maximum thickness of base plate(s)	$t_{fix,max}$	mm	20	30	50	40	60	50	100
		in.	0.79	1.18	1.97	1.57	2.36	1.97	3.94
Minimum thickness of concrete member[1]	h_{min}	mm	200 - t_{fix}	230 - t_{fix}	250 - t_{fix}	310 - t_{fix}	330 - t_{fix}	400 - t_{fix}	450 - t_{fix}
		in.	7.9 - t_{fix}	9.1 - t_{fix}	9.8 - t_{fix}	12.2 - t_{fix}	13.0 - t_{fix}	15.7 - t_{fix}	17.7 - t_{fix}

For inch units: 1 mm = 0.03937 inches

[1] h_{min} is dependent on the actual thickness of base plate(s) t_{fix}

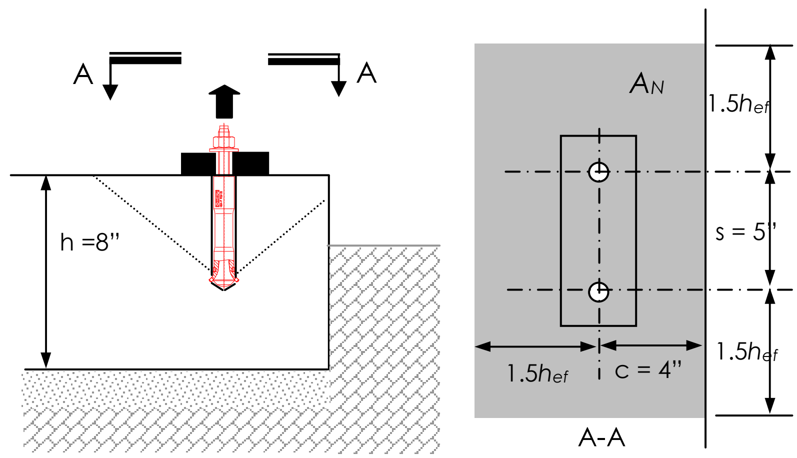
e.g. HDA-T 22-M12x125/50 : t_{fix} = 20 mm → h_{min} = 250 - 20 = 230 mm

t_{fix} = 50 mm → h_{min} = 250 - 50 = 200 mm

FIGURE 3—HDA Sample calculation in accordance with ACI 349-01 Appendix B

Given:

2 HDA-P M10 anchors under static tension load as shown.
h_{ef} = 3.94 in. (100 mm).
Slab on grade, f'_c = 3,000 psi.
No supplementary reinforcing.
Assume cracked concrete
Calculate the design strength in tension for this configuration.



Calculation per ACI 349-01 Appendix B and this document.	**Code Ref.**	**Guide Ref.**
Step 1. Calculate steel strength of anchor in tension $N_s = nA_{se}f_{ut} = 2\,x\,10{,}431 = 20{,}862\,lb$	B.5.1.2	Table 1
Step 2. Calculate steel capacity $\phi N_S = 0.80\,x\,20{,}862 = 16{,}689\,\text{lb}$	B.4.4 a	Table 1
Step 3. Calculate concrete breakout strength of anchor in tension $N_{cbg} = \frac{A_N}{A_{No}}\psi_1\psi_2\psi_3 N_b$	B.5.2.1b	-
Step 3a. Check $1.5h_{ef} = 1.5(3.94) = 5.91\text{ in} > c$ $3.0h_{ef} = 3(3.94) = 11.82\text{ in} > s$	B.5.2.1	Table 1
Step 3b. Check s_{min} = 4 in. < s = 5 in., c_{min} = 3-1/8 in. < c = 4 in., h_{min} = 7.1 in. < h = 8 in.	B.8	Table 1
Step 3c. Calculate A_{No} and A_N for the anchorage: $A_{No} = 9h_{ef}^2 = 9 \times (3.94)^2 = 139.7\text{ in}^2$ $A_N = (1.5h_{ef} + c)(3h_{ef} + s) = [1.5 \times (3.94) + 4][3 \times (3.94) + 5] = 166.7\text{ in}^2 < 2 \cdot A_{No}$ ∴ ok	B.5.2.1	Table 1
Step 3d. Calculate ψ_1 : $e'_N = 0$ ∴ $\psi_1 = 1.0$	B.5.2.4	Table 1
Step 3e. Calculate N_b: $N_b = k\sqrt{f'_c}\,h_{ef}^{1.5} = 24\,x\sqrt{3{,}000}\,x\,3.94^{1.5} = 10{,}280$ [lb]	B.5.2.2	Table 1
Step 3f. Calculate modification factor for edge distance: $\psi_2 = 0.7 + 0.3\frac{4}{1.5(3.94)} = 0.90$	B.5.2.5	Table 1
Step 3g. For cracked concrete: $\psi_3 = 1.0$	B.5.2.6	Table 1
Step 3h. Calculate ϕN_{cbg}: $\phi N_{cbg} = 0.75\,x\frac{166.7}{139.7}x1x0.90x1x10{,}280 = 8{,}280$ [lb] governs	B.5.2.1b	Table 1
Step 4: Calculate pull out strength: $\psi_3 N_{p,cr}$ $\psi_3 nN_{p,cr} = N_{pn}$ = 1.0 x 2 x 8,992 lb = 17,984 lb; ψ_3 = 1.0 (cracked concrete) ϕN_{pn} = 0.75 x 17,984 lb = 13,488 lb does not control	B.5.3	Table 1
Step 5. Ductility check according to B.3.6.1: For tension: 0.85 min[N_{cbg} ; N_{pn}] ≥ A_{se} f_{uta} => 0.85 (N_{cbg}) = 0.85 (11,038 lb) = 9,382 lb < 20,862 lb ∴ ductility not met B.3.6.3 requires an additional reduction factor of 0.6 for non-ductile anchors 0.6 x ϕN_{cbg} = 0.6 x 8,280 = 4,968 lb Note: According to B.3.6.2, alternatively the attachment / base plate can be designed to yield at a load level of 75% of the anchor design strength. In this case, the 0.6 factor would not have to be applied.	B.3.6.1 B.3.6.3 / B.4.1	Table 1