CABLE-TITE

SECURE HOME TIE-DOWN SYSTEMS

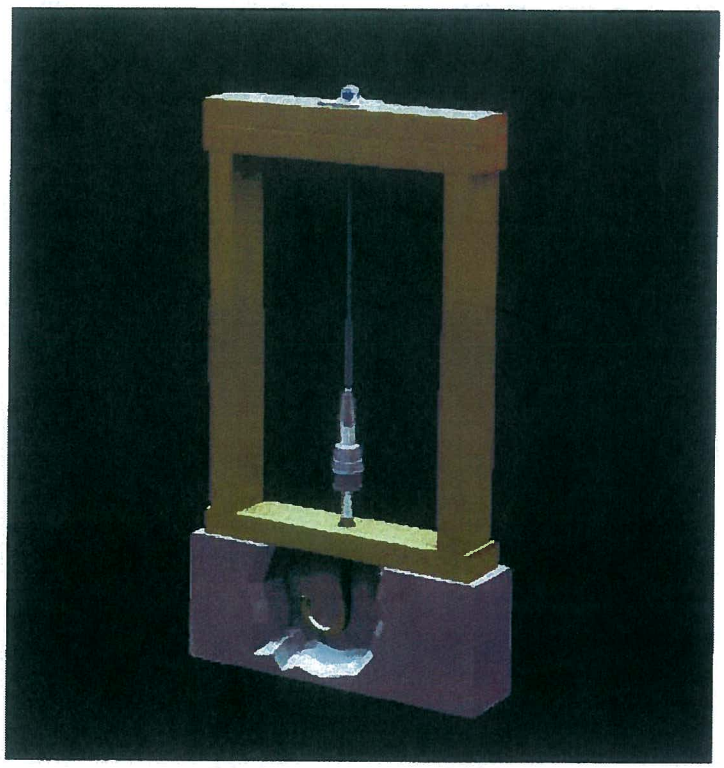


Table of Contents

Engineering Analysis of Cable-Tite Anchoring System

Introduction

The following report contains an engineering analysis performed by MLAW Consultants and Engineers for the purpose of determining parameters for a typical installation of the Cable-Tite anchoring system in various windzones ranging from 110 to 130 mph design wind speeds such as those found in the Seaward, Inland II and Inland I regions of the Texas coastal area. The intent of the analysis is to compare the performance of the anchoring system against the current model building code to determine compliance in the coastal wind zones for the purpose of obtaining TDI approval for use in these regions. The analysis covers each of the various components of the assembly not previously addressed in the Smith-Emery report L-09-830. Component calculations are shown to determine the maximum allowable capacity of the system based on the load capacity of the anchors, which are established as the limiting component. Parameters representing a semi-typical structure are then utilized in order to ascertain the more conservative wind loads that could be encountered during a design of the uplift resisting system. Finally, the findings are used to make recommendations regarding the foundation connection and maximum spacing of the Cable-Tite anchoring system in each of the three coastal wind zones. These recommendations are intended for a typical fully sheathed 40' x 60' structure under 35' in height having an importance factor of I or II as defined by ASCE 7-05 Table 1.1 and meeting the requirements of ASCE 7-05 Section 6.4.1.1. Buildings not meeting these requirements will require further analysis by a professional engineer before installation specifications can be made.

All calculations are in accordance with the applicable code, as referenced by the model 2009 International Building Code. Based on the data provided by Smith-Emery Laboratories, engineering statistics are employed to derive the maximum cable tension that could be expected due to the installation process, prior to any wind load. The top plate and stud column capacities are determined in accordance with the design procedures provided in the National Design Specification (NDS) 2005. Anchor capacities for a standard cast-in-place hooked anchor, as well as an adhesive anchor, are determined from ACI 318-08 in conjunction with ICC-ES AC308 Acceptance Criteria for Post-Installed Adhesive Anchors In Concrete Elements. Wind loads are determined using Method 1 of ASCE 7-05. The wall deflection between installed cable systems is calculated using the wood diaphragm relationships provided by the 2009 IBC. For simplicity, all capacities and loads are derived using LRFD.

In summary, the engineering analysis demonstates that even in the 130 mph wind zone, the Cable-Tite anchoring system does provide an effective alternative to conventional metal connectors below the top plate. Installed per the recommendations resulting from the analysis, the anchoring system will exceed all of the current code performance requirements relating to wind uplift resistance. However, it should be noted that this product is intended for the purpose of providing resistance to uplift. It is not intended for lateral restraint. Therefore all calculations related to the lateral aspects of the Main Wind Force Resisting System have been omitted, as it is expected that the design of the structure will employ other means to provide the necessary lateral stability.

Product Description

Cable-Tite is a patented system using cable to anchor the top plate to the foundation in typical wood stud wall construction. A cast steel Cable-Tite nut attaches to a concrete anchor bolt. A cast steel cam-locking cap holds a cable vise facing upward. The vise is used to hold 1/4" extra high strength steel cable. The cable extends upward to another opposite facing cable vise at the top plate. The top vise is held in palce by a 3" square steel plate. Once these are securely in place and hand tightened, a 120 degree turn on the cap locks the assembly permanently in place with an initial tensile load of 600-800 lbs.

The specifications for the anchor nut, locking cap, top plate, cable and cable vise are as follows:

- **Anchor Nut**

This nut is 2" H and 1 1/2" round. The threads are 5/8" to screw onto the anchor bolt. It is made of industrial grade cast steel IC-1020, ASTM A-148 grade 80/40 and 125 yellow zinc coated for weatherization. The CT logo is cast into it.

- **Locking Cap**

The cap is 1 1/2" H by 1 3/4" round. It attaches over the nut, locks, and holds the bottom cable vise in place. It is made of industrial grade cast steel IC-1020, ASTM A-148 grade 80/40 and 125 yellow zinc coated for weatherization. The CT logo is cast into it.

- **Top Cap**

The top plate is 3" square and 5/8" H. It has small knurl teeth on the bottom side for gripping the wooden top plate. It holds the top cable vise in place. It is made of industrial grade cast steel IC-1020, ASTM A-148 grade 80/40 and 125 yel low zinc coated for weatherization. The CT logo is cast into it.

- **Cable Vises**

Each of the two cable vises are 4" H and 1" round and are installed facing opposite directions to hold the cable taunt. The inside teeth are made of galvanized steel IC-1020 and the outside covering is galvanized aluminum.

- **Cable**

The cable is 1/4" 7-strand extra high strength steel, made to ASTM A-475. It is cut to length on site, so lengths vary.

Component Calculations

■ Calculation of service load in cable incurred during installation tensioning

From Smith-Emery report L-09-830, dated May 11, 2009, Table 21 indicates the residual load after 0.078" of settlement/shrinkage for three test specimens.

$x_1 = 229$ lbs

$x_2 = 143$ lbs

$x_3 = 143$ lbs

The mean value is:

$$\overline{x} = \frac{\sum_{i=1}^{n} x_i}{n} = 161.3 \text{ lbs}$$

The standard deviation for the sample is

$$s = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \overline{x})^2}{n-1}} = 60.6 \text{ lbs}$$

With 95% confidence, the prediction bound to determine the maximum installation tension in any observed sample is

$T_s = \overline{x} + t_\alpha s \sqrt{1 + \frac{1}{n}} = 365.7$ lbs $t_\alpha = 2.92$ for 5% and 2 degrees of freedom   Standard t-table

■ Allowable uplift as controlled by wall top plate

Assumptions

1. Typical SPF Utility grade wall top plate
2. A maximum load of 365.7 lbs due to installation tensioning exists prior to any additional loading
3. At area supporting bearing plate, the wall top plate receives load only from the bearing plate.
4. Critical design load combination is 1.6W + 1.2D
5. Design loads are calculated using LRFD

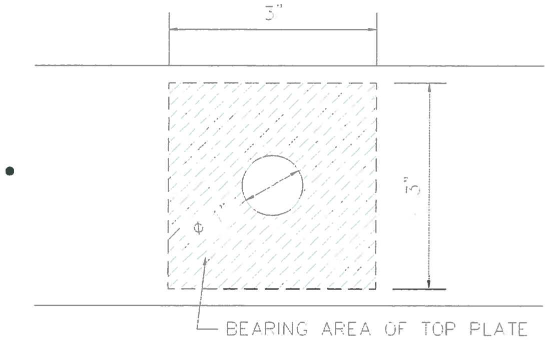
The allowable load supported by the top plate is calculated from

$$1.6\,W + 1.2\,(D + T_s) = F_{c\perp}\, C_b\, \phi K_F\, \lambda\, A_b$$

$T_s = 365.7$ lbs	Maximum installation tension in cable	
$F_{c\perp} = 425$ psi	Compression perpendicular to grain	NDS 2005 Table 4A
$C_b = \frac{3+0.375}{3} = 1.875$	Bearing Area Factor	NDS 2005 (3.10-2)

$\phi = 0.9$	Resistance Factor	NDS 2005 Table N2
$K_F = 1.875/\phi$	Format Conversion Factor	NDS 2005 Table N1
$\lambda = 1.0$	Time Effect Factor	NDS 2005 Table N3
$A_b = \frac{3 \cdot 3 - \pi(1)^2}{4} = 8.21 \text{ in}^2$	Area of bearing plate	
$1.6\,W + 1.2\,D = 6925$ lbs	Allowable factored uplift	

Note that because the individual studs adjacent the anchoring system provide approximately 28% more bearing area than the metal bearing plate, the load capacity allowed by the studs exceeds that of the bearing plate. Additionally, the NDS 2005 tabulated value for compression parallel to grain exceeds that of compression perpendicular to grain. Because the studs receive support throughout their length via connection to the drywall and exterior sheathing, the column stability factor is 1.0 (NDS 2005 3.7.1.1). This condition makes a column check for the studs extraneous, as it is clear that their compressive capacity exceeds that of the top plate.



■ Allowable uplift as controlled by hooked precast anchor

Assumptions
1. Calculated capacity assumes cracked concrete section
2. Concrete compressive strength is 2500 psi after 28 days
3. Anchor is a hooked 5/8"ϕ x 12" anchor with minimum 2" hook
4. Anchor steel is A307 Grade C (36 ksi yield)
5. Minimum edge distance is 1.75"
6. Anchor is loaded in tension only
7. Supplementary reinforcement is not present
8. Critical design load combination is 1.6W + 1.2D
9. Design loads are calculated using LRFD

- **Steel strength of a single anchor in tension**

$\phi N_{sa} = n\, f_{uta}\, A_{se,N} = 11\,594$ lbs		ACI 318-08 (D-3)
$\phi = 0.75$	Strength reduction factor	ACI 318-08 D.4.4
$n = 1$	Number of anchors	
$A_{se,N} = 0.226\ \text{in}^2$	Effective area of anchor	ASTM F1554 Table 4
$f_{uta} = \text{MIN}(1.9\, f_{ya},\ 125\,000)$	Specified tensile strength of steel	ACI 318-08 D.5.1.2
$f_{ya} = 36\,000$ psi	Yield strength of anchor	ASTM F1554

- **Concrete breakout strength of an anchor in tension**

$\phi N_{cb} = \frac{A_{Nc}}{A_{Nco}}\, \psi_{ed,N}\, \psi_{c,N}\, \psi_{cp,N}\, N_b = 9290$ lbs		ACI 318-08 (D-4)
$\phi = 0.70$	Strength reduction factor	ACI 318-08 D.4.4
$A_{Nc} = (2 \times 1.5\, h_{ef})\,(c_{a1} + 1.5\, h_{ef})$ $= 257\ \text{in}^2$ RD.5.2.1	Projected concrete failure area	ACI 318-08 Fig
$A_{Nco} = 9\, h_{ef}^2 = 441\ \text{in}^2$	Projected concrete failure area	ACI 318-08 (D-6)
$N_b = \lambda\, k_c\, h_{ef}^{1.5} \sqrt{f_{c,prime}}$ $= 22\,224$ lbs	Basic concrete breakout strength, cracked concrete	ACI 318-08 (D-7)
$c_{a1} = 1.75$ in	Distance from center of anchor to edge of concrete	
$c_{a,min} = 1.75$ in	Distance from center of anchor to edge of concrete	
$e_{N,prime} = 0$ in	Horizontal distance between tension load and center of anchor	
$f_{c,prime} = 2500$ psi	Compressive strength of concrete	
$h_{ef} = 7$ in	Effective embedment depth of anchor	
$k_c = 24$	Coefficient for basic breakout strength, cast-in anchor	ACI 318-08 D.5.2.2
$\lambda = 1.0$	Factor for lightweight concrete	
$\psi_{ed,N} = 0.7 + 0.3\, \frac{c_{a,min}}{1.5\, h_{ef}} = 0.75$	Factor for edge effects	ACI 318-08 (D-11)
$\psi_{c,N} = 1.0$	Factor for absence of cracks in concrete	ACI 318-08 D.5.2.6
$\psi_{cp,N} = 1.0$	Factor for post installed anchors in uncracked concrete	ACI 318-08 (D-12)

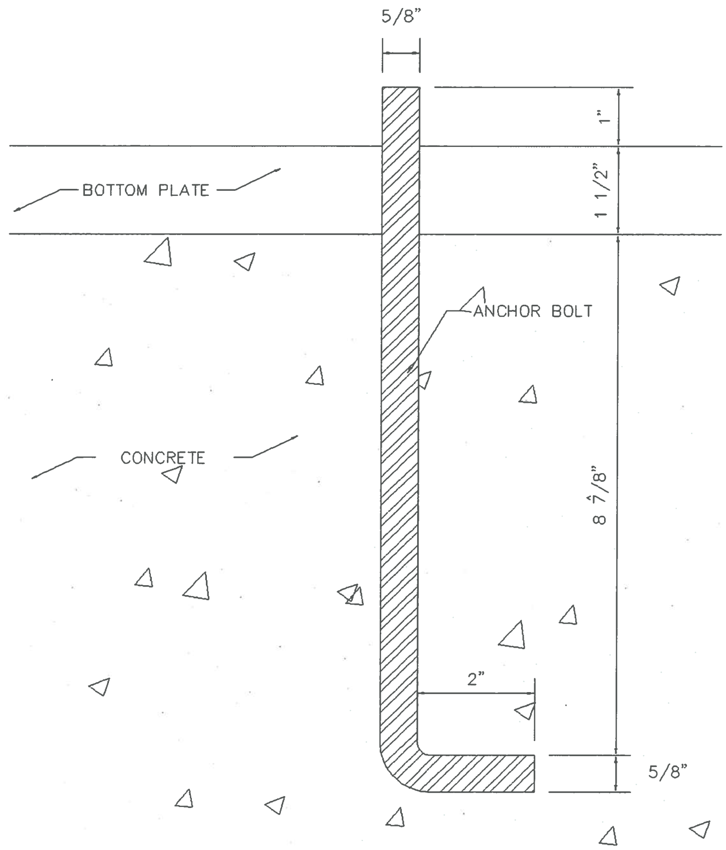
- **Pullout strength of an anchor in tension**

$\phi N_{pn} = \psi_{c,p}\, N_p = 1969$ lbs		ACI 318-08 (D-14)
$\phi = 0.70$	Strength modification factor	ACI 318-08 D.4.4
$N_p = 0.9\, f_{c,prime}\, e_h\, d_a = 2813$ lbs	Basic pullout strength of hooked anchor	ACI 318-08 (D-16)
$d_a = \frac{5}{8}$ in	Diameter of anchor	
$e_h = 2$ in	Distance from inner surface of shaft to tip of hook	
$\psi_{c,p} = 1.0$	Factor for absence of cracks in concrete	ACI 318-08 D.5.3.6

- **Summary of hooked precast anchor calculations**

The controlling failure mode is anchor pullout due to crushing of the concrete above the hook. Allowing for the force due to installation tension, the allowable factored design uplift load as limited by the strength of the cast in place hooked anchor is found to be:

$0.9\,D + 1.6\,W \leq \phi \mathrm{N}_{\mathrm{pn}} - 1.2\,T_s \leq 1530$ lbs



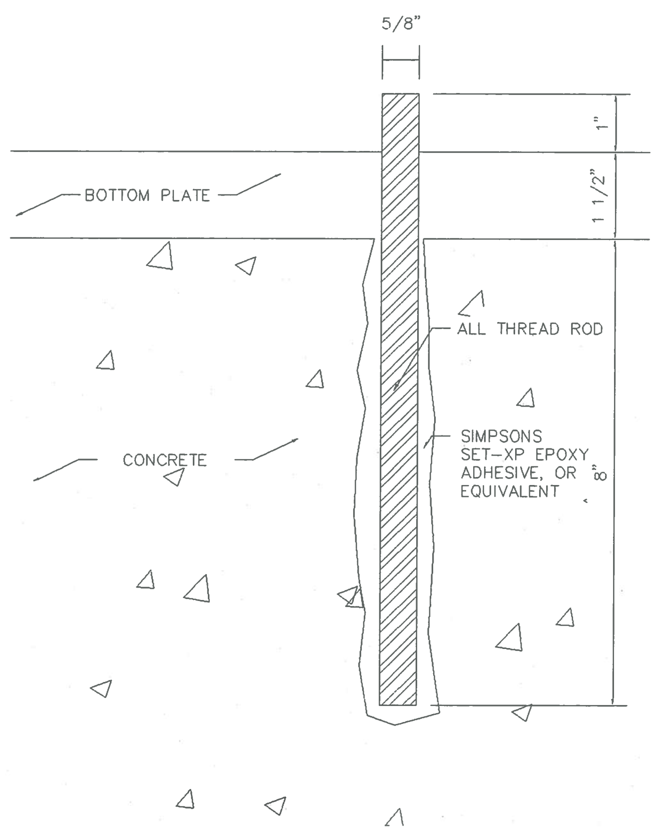
■ Allowable uplift as controlled by adhesive anchor

Assumptions
1. Calculated capacity assumes cracked concrete section
2. Concrete compressive strength is 2500 psi after 28 days
3. Anchor is a 5/8"ϕ x 10.5" all-thread-rod
4. Anchor steel is A307 Grade C (36 ksi yield)
5. Adhesive is Simpson SET-XP or equivalent
6. Continuous inspection during anchor installation
7. Maximum short and long term temperatures do not exceed 110° F and 75° F, respectively
8. Minimum edge distance is 1.75"
9. Anchor is loaded in tension only
10. Supplementary reinforcement is not present
11. Critical design load combination is 1.6W + 1.2D
12. Design loads are calculated using LRFD

■ Summary of adhesive anchor calculations

Based on "Anchor Designer for ACI 318 (Version 4.2.0.2) software provided by Simpson Strong-Tie, the connection is limited by the adhesive capacity to a value of 3442 lbs. (See accompanying calculations.) Allowing for the force due to installation tension, the allowable factored design uplift load as limited by the strength of the adhesive anchor is found to be:

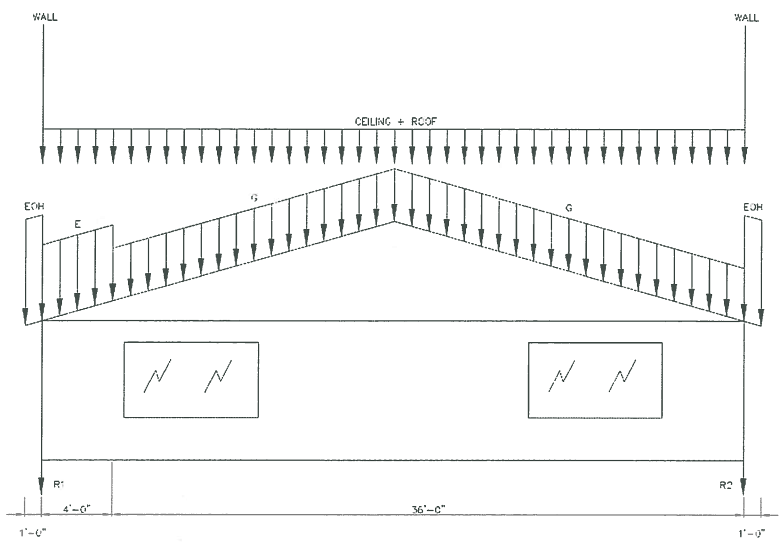
$0.9\,D + 1.6\,W \leq 3442 - 1.2\,T_s \leq 3003$ lbs



Uplift Calculations

Assumptions

1. All loads transfer to exterior walls
2. Building meets all requirements of ASCE 7-05 6.4.1.1
3. Importance factor of 1.0
4. Topographic factors do not affect the design wind pressure
5. Roof pitch of 20°
6. Exposure C assumed for Seaward wind zone only
7. Uplift transfers entirely into anchors, unaided by existing foundation anchorage
8. Dead loads are minimal, e.g. composition roof, exterior siding on walls



Vertical Pressures, ASCE 7−02 Fig 6−2			
	EOH	E	G
Seaward	−60.9	−43.5	−30.2
Inland I	−38.4	−27.4	−19.1
Inland II	−32.3	−23.1	−16.0

Distributed Dead Loads	
Wall, W	80 plf
Ceiling, C	10 psf
Roof, R	10 psf

- **Reaction at anchor due to wind pressure**

$$\sum M_2 = 0: \quad -\text{EOH}\cdot 1\cdot 0.5 + \text{EOH}\cdot 1\cdot 40.5 + G\cdot 36\cdot 18 + E\cdot 4\cdot 38 + R_{1,\text{wind}}\cdot 40 = 0$$

$$R_{1,\text{wind}} = -\frac{1}{5}\left(5\,\text{EOH} + 81\,G + 19\,E\right)$$

- **Reaction at anchor due to dead load**

$$\sum M_2 = 0: \quad R\cdot 42\cdot 20 + C\cdot 40\cdot 20 + W\cdot 40 + R_{1,\text{dead}}\cdot 40 = 0$$

$$R_{1,\text{dead}} = -21\,R - 20\,C - W$$

The controlling load combination is $U = 0.9\,D + 1.6\,W$ ACI 318-08 (9-6)

$$R_1 = 0.9[-21\,R - 20\,C - W] + 1.6\left[-\frac{1}{5}\left(5\,\text{EOH} + 81\,G + 19\,E\right)\right]$$

Summary of uplift and resulting recommended maximum spacing for each wind zone and anchor combination

Uplift and Recommended Spacing Results			
	Seaward	Inland I	Inland II
Uplift at Bottom Plate	704 plf	282 plf	166 plf
Spacing w/Adhesive Anchor	4 ft	8 ft	16 ft
Spacing w/Hooked Anchor	2 ft	4 ft	8 ft

Deflection Calculations

- **Exterior wall deflection between installed cable anchor systems**

Assumptions

1. Wall is sheathed with uniformly fastened 32/16 rated OSB, one side only
2. Diaphragm chords are 2x4 SPF lumber
3. Spacing does not exceed that recommended in the previous calculation, therefore 16 ft at 166 plf controls
4. Deflection is limited to L/240
5. Chord splices are near anchor locations and therefore contribute a negligible amount to the deflection

$\Delta = \frac{5 v L^3}{8 E A b} + \frac{v L}{4 G_t} + 0.188\, L\, e_n$	diaphragm deflection, omitting chord splice term	IBC 2009 (23-1)
$L = 16$ ft	span of diaphragm	
$w = 166$ plf	total uplift distributed along wall	
$v = \frac{L w}{b} = 332$ plf	maximum diaphragm shear	
$E = 1\,200\,000$ psi	elastic modulus of SPF chord	NDS 2005 Table 4A
$A = 2 \cdot 1.5 \cdot 3.5 = 10.5\ \text{in}^2$	cross-sectional area of chord	
$b = 8$ ft	diaphragm width	
$e_n = 0.0132$ in	fastener deformation factor	IBC 2009 TABLE 2305.2(1)
$G_t = 83\,500$ lb/in	modulus of rigidity for OSB	IBC 2009 TABLE 2305.2(2)

$\Delta = 0.064$ in

$\Delta_{\text{allow}} = 12\, L / 240 = 0.8$

$\Delta \le \Delta_{\text{allow}}$, OK

- **Deflection of top plate at location of bearing plate**

Assumptions

1. Studs are 16" o.c., max
2. Top plate is (2) 2x4, SPF, min

$P \le 4 \cdot 704 = 2816$ lbs	maximum calculated load at recommended spacing	
$E = 1\,200\,000$ psi	elastic modulus of top plate	NDS 2005 Table 4A
$I = \frac{1}{12} 3.5 \cdot 3^3 = 7.875\ \text{in}^4$	moment of inertia about horizontal axis	

$\Delta_{\text{max}} = \frac{P L^3}{48 E I} = 0.025$ in

$\Delta_{\text{allow}} = \frac{16}{240} = 0.06$ in

$\Delta_{\text{max}} \le \Delta_{\text{allow}}$, OK

Installation

■ General Installation Requirements

The Cable-Tite Anchoring System shall be installed in accordance with the requirements and provisions of the International Residence Code (IRC) and the International Building Code (IBC) and the Texas Revisions. Cable-Tite shall be installed according to the manufacturer's installation instructions. A Texas licensed professional engineer and a qualified Windstorm inspector shall be present at the job site to insure the proper installation method is followed. The engineer will assure that the design load requirements and the other construction components meet the uplift requirements for the structure.

■ Top Plate

The roof rafters or trusses shall be attached to the double top plate of the stud wall with approved metal connectors. These connectors will meet or exceed the uplift value of the stud wall, as described in the manufacturer's published guide and shall be corrosion resistant. When installed correctly, they will transfer the load of the roof system onto the stud wall. Cable-Tite will transfer the uplift load of the wall system onto the foundation.

■ Wood Framing

The wood stud walls shall be a minimum of 2" nominal thickness and centered in accordance with windstorm codes. They shall have a minimum of 2" nominal thickness for the sill plate and a double top plate. All wood framed walls and components will be in accordance with the Wood Frame Construction Manual (WFCM) for the corresponding wind region.

■ Foundation

Concrete Slab Foundation: The foundation anchor bolts are 5/8" diameter 10" x 5/8" cast-in-place hooked anchors or 5/8" diameter 10-1/2" adhesive anchors, depending on the site-specific engineering specifications. The anchors are embedded so as to allow 1" of threads above the sill plate for the anchor nut to fasten. Minimum concrete compressive strength shall be 2500 psi. The minimum distance from the edge is 1-3/4".
Masonry Block Foundation: The specified cast-in-place or adhesive anchor bolt will be embedded into a cell that is solid filled with concrete, 2500 psi or greater, and poured to the footer. The embedment shall be adjusted to allow 1" of exposure above the sill plate.
Precast Concrete Beams: The specified anchor shall be embedded in a concrete beam at such distance to allow 1" of exposure above the sill plate.
Adhesive Anchors: Where adhesive anchors are specified, they shall be installed according to the manufacturer's requirements. The adhesive shall be approved for use in cracked concrete and be compliant with IBC 2006.

All foundation and anchor bolt spacing shall be done in accordance with WFCM for the applicable wind region. The engineer will determine the location and spacing of the Cable-Tite anchoring systems.

Anchor Calculations

Anchor Designer for ACI 318 (Version 4.2.0.2)

Job Name : 1018000043 Cable-Tite

Date/Time : 5/3/2010 9:01:05 AM

1) Input

Calculation Method : ACI 318 Appendix D For Cracked Concrete

Calculation Type : Analysis

a) Layout

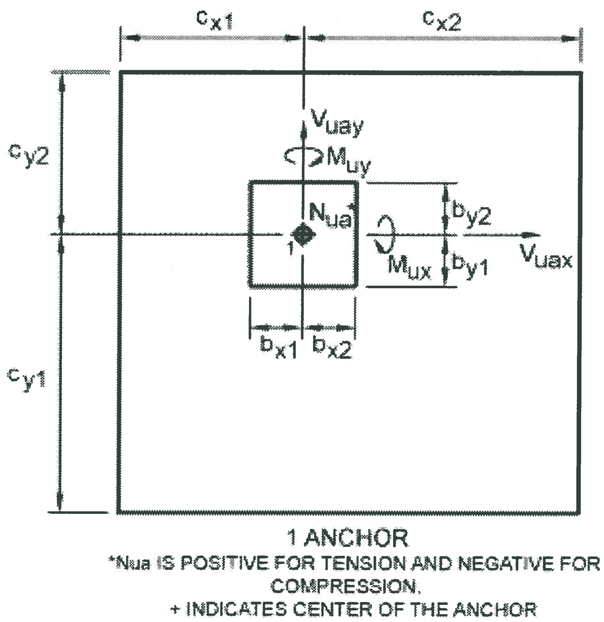
Anchor : 5/8" SET-XP

Number of Anchors : 1

Steel Grade: A307 GR. C

Embedment Depth : 8 in

Built-up Grout Pads : No



Anchor Layout Dimensions :

c_{x1} : 1.75 in

c_{x2} : 9 in

c_{y1} : 9 in

c_{y2} : 8 in

b) Base Material

Concrete : Normal weight

f'_c : 2500.0 psi

Cracked Concrete : Yes

$\Psi_{c,V}$: 1.00

Condition : B tension and shear

ϕF_p : 1381.3 psi

■ Cable-Tite Installation Instructions

1. Secure the anchor nut to the existing anchor bolt. Use a wrench to get the nut snug with the sill plate.
2. Cut the cable to length. Measure from the sill plate to the top of the stud wall and add 6 inches.
3. Feed a cable vise through the bottom of the locking cap. Align the stop notch with the cutout in the cap.
4. Push one end of the cable into the vise. DO NOT PUSH IT PAST THE END OF THE VISE.
5. Place the cap over the top of the anchor nut, and twist it, but do not lock. Be careful to handle the cap only and not the vise to keep from pushing the cable too deep. Use one hand to pull upward on the cable, and the other to twist on the cap. The cap should fit loosely.
6. Drill a one inch hole in the top plate directly above.
7. Feed the upper vise into the steel top plate. Align the notches. The bottom of the steel top plate has knurling to grip the wood. Sit the assembly into the hole.
8. Secure the top plate with (2) 1-1/2 inch screws or (2) 6d nails.
9. Feed the cable into the upper cable vise. Grip excess cable at the top and work cable and vise until it is as tight as possible.
10. Use two wrenches to lock the cap and nut. This is a 120 degree turn. It will click and the logos will align.

Installation shall be done according to these instructions. Instructions are shipped to each job site with the Cable-Tite order, and shall be available during installation.

Thickness, h : 24 in
Supplementary edge reinforcement : No
Hole Condition : Dry Concrete
Inspection : Continuous
Temperature Range : 1 (Maximum 110 °F short term and 75 °F long term temp.)

c) Factored Loads

Load factor source : ACI 318 Section 9.2

N_{ua} : 3442 lb

V_{uax} : 0 lb

V_{uay} : 0 lb

M_{ux} : 0 lb*ft

M_{uy} : 0 lb*ft

e_x : 0 in

e_y : 0 in

Moderate/high seismic risk or intermediate/high design category : No
Anchor w/ sustained tension : No
Anchors only resist wind and/or seismic loads : Yes
Apply entire shear load at front row for breakout : No

d) Anchor Parameters

From C-SAS-2009:

Anchor Model = SETXP d_o = 0.625 in

Category = 1 h_{ef} = 8 in

h_{min} = 11.125 in c_{ac} = 24 in

c_{min} = 1.75 in s_{min} = 3 in

Ductile = Yes

2) Tension Force on Each Individual Anchor

Anchor #1 N_{ua1} = 3442.00 lb

Sum of Anchor Tension ΣN_{ua} = 3442.00 lb

e'_{Nx} = 0.00 in

e'_{Ny} = 0.00 in

3) Shear Force on Each Individual Anchor

Resultant shear forces in each anchor:

Anchor #1 V_{ua1} = 0.00 lb (V_{ua1x} = 0.00 lb , V_{ua1y} = 0.00 lb)

Sum of Anchor Shear ΣV_{uax} = 0.00 lb, ΣV_{uay} = 0.00 lb

e'_{Vx} = 0.00 in

e'_{Vy} = 0.00 in

4) Steel Strength of Anchor in Tension [Sec. D.5.1]

$N_{sa} = nA_{se}f_{uta}$ [Eq. D-3]

Number of anchors acting in tension, n = 1

N_{sa} = 13110 lb (for a single anchor) [C-SAS-2009]

ϕ = 0.75 [D.4.4]

ϕN_{sa} = 9832.50 lb (for a single anchor)

5) Concrete Breakout Strength of Anchor in Tension [Sec. D.5.2]

$N_{cb} = A_{Nc}/A_{Nco}\Psi_{ed,N}\Psi_{c,N}\Psi_{cp,N}N_b$ [Eq. D-4]

Number of influencing edges = 4

h_{ef} (adjusted for edges per D.5.2.3) = 6.000 in

A_{Nco} = 324.00 in^2 [Eq. D-6]

A_{Nc} = 182.75 in^2

Smallest edge distance, $c_{a,min}$ = 1.75 in

$\Psi_{ed,N}$ = 0.7583 [Eq. D-10 or D-11]

Note: Cracking shall be controlled per D.5.2.6

$\Psi_{c,N}$ = 1.0000 [Sec. D.5.2.6]

$\Psi_{cp,N}$ = 1.0000 [Eq. D-12 or D-13]

$N_b = k_c\sqrt{f'_c}\,h_{ef}^{1.5}$ = 12492.40 lb [Eq. D-7]

k_c = 17 [Sec. D.5.2.6]

N_{cb} = 5343.41 lb [Eq. D-4]

ϕ = 0.65 [D.4.4]

ϕN_{cb} = 3473.22 lb (for a single anchor)

6) Adhesive Strength of Anchor in Tension [Sec. D.5.3 (AC308 Sec.3.3)]

$\tau_{k,cr}$ = 718 psi [C-SAS-2009]

k_{cr} = 17 [C-SAS-2009]

h_{ef} (unadjusted) = 8 in

$N_{ao} = \tau_{k,cr}\pi\, d_o h_{ef}$ = 11278.32 lb [Eq. D-16f]

$\tau_{k,uncr}$ = 2263.00 psi for use in [Eq. D-16d]

$s_{cr,Na} = \min[20d_o\sqrt{(\tau_{k,uncr}/1450)}\,,\ 3h_{ef}]$ = 15.616 in [Eq. D-16d]

$c_{cr,Na} = s_{cr,Na}/2$ = 7.808 in [Eq. D-16e]

$N_a = A_{Na}/A_{Nao}\Psi_{ed,Na}\Psi_{p,Na}N_{ao}$ [Eq. D-16a]

A_{Nao} = 243.86 in^2 [Eq. D-16c]

A_{Na} = 149.26 in^2

Smallest edge distance, $c_{a,min}$ = 1.75 in

$\Psi_{ed,Na}$ = min[0.7+0.3$c_{a,min}$/$c_{cr,Na}$, 1.0] = 0.7672 [Eq. D-16m]

$\Psi_{p,Na}$ = 1.0000 [Sec. D.5.3.14]

N_a = 5296.30 lb [Eq. D-16a]

ϕ = 0.65 [C-SAS-2009]

ϕN_a = 3442.59 lb (for a single anchor)

7) Side Face Blowout of Anchor in Tension [Sec. D.5.4]

Concrete side face blowout strength is only calculated for headed anchors in tension close to an edge, $c_{a1} < 0.4h_{ef}$. Not applicable in this case.

8) Steel Strength of Anchor in Shear [Sec D.6.1]

V_{sa} = n0.6$A_{se}f_{uta}$ [Eq. D-20]

V_{sa} = 7865.00 lb (for a single anchor) [C-SAS-2009]

ϕ = 0.65 [D.4.4]

ϕV_{sa} = 5112.25 lb (for a single anchor)

9) Concrete Breakout Strength of Anchor in Shear [Sec D.6.2]

Concrete breakout strength has not been evaluated against applied shear load(s) per user option. Refer to Section D.4.2.1 of ACI 318 for conditions where calculations of the concrete breakout strength may not be required.

10) Concrete Pryout Strength of Anchor in Shear [Sec. D.6.3]

V_{cp} = min[$k_{cp}N_a$,$k_{cp}N_{cb}$] [Eq. D-30a]

k_{cp} = 2 [Sec. D.6.3.2]

N_a = 5296.30 lb (from Section (6) of calculations)

N_{cb} = 5343.41 lb (from Section (5) of calculations)

V_{cp} = 10592.60 lb

ϕ = 0.70 [D.4.4]

ϕV_{cp} = 7414.82 lb (for a single anchor)

11) Check Demand/Capacity Ratios [Sec. D.7]

Tension

- Steel : 0.3501
- Breakout : 0.9910
- Adhesive : 0.9998

- Sideface Blowout : N/A

Shear

- Steel : 0.0000
- Breakout : N/A
- Pryout : 0.0000

V.Max(0) <= 0.2 and T.Max(1) <= 1.0 [Sec D.7.1]

Interaction check: PASS

Use 5/8" diameter A307 GR. C SET-XP anchor(s) with 8 in. embedment

t Table

cum. prob	$t_{.50}$	$t_{.75}$	$t_{.80}$	$t_{.85}$	$t_{.90}$	$t_{.95}$	$t_{.975}$	$t_{.99}$	$t_{.995}$	$t_{.999}$	$t_{.9995}$
one-tail	**0.50**	**0.25**	**0.20**	**0.15**	**0.10**	**0.05**	**0.025**	**0.01**	**0.005**	**0.001**	**0.0005**
two-tails	**1.00**	**0.50**	**0.40**	**0.30**	**0.20**	**0.10**	**0.05**	**0.02**	**0.01**	**0.002**	**0.001**
df											
1	0.000	1.000	1.376	1.963	3.078	6.314	12.71	31.82	63.66	318.31	636.62
2	0.000	0.816	1.061	1.386	1.886	2.920	4.303	6.965	9.925	22.327	31.599
3	0.000	0.765	0.978	1.250	1.638	2.353	3.182	4.541	5.841	10.215	12.924
4	0.000	0.741	0.941	1.190	1.533	2.132	2.776	3.747	4.604	7.173	8.610
5	0.000	0.727	0.920	1.156	1.476	2.015	2.571	3.365	4.032	5.893	6.869
6	0.000	0.718	0.906	1.134	1.440	1.943	2.447	3.143	3.707	5.208	5.959
7	0.000	0.711	0.896	1.119	1.415	1.895	2.365	2.998	3.499	4.785	5.408
8	0.000	0.706	0.889	1.108	1.397	1.860	2.306	2.896	3.355	4.501	5.041
9	0.000	0.703	0.883	1.100	1.383	1.833	2.262	2.821	3.250	4.297	4.781
10	0.000	0.700	0.879	1.093	1.372	1.812	2.228	2.764	3.169	4.144	4.587
11	0.000	0.697	0.876	1.088	1.363	1.796	2.201	2.718	3.106	4.025	4.437
12	0.000	0.695	0.873	1.083	1.356	1.782	2.179	2.681	3.055	3.930	4.318
13	0.000	0.694	0.870	1.079	1.350	1.771	2.160	2.650	3.012	3.852	4.221
14	0.000	0.692	0.868	1.076	1.345	1.761	2.145	2.624	2.977	3.787	4.140
15	0.000	0.691	0.866	1.074	1.341	1.753	2.131	2.602	2.947	3.733	4.073
16	0.000	0.690	0.865	1.071	1.337	1.746	2.120	2.583	2.921	3.686	4.015
17	0.000	0.689	0.863	1.069	1.333	1.740	2.110	2.567	2.898	3.646	3.965
18	0.000	0.688	0.862	1.067	1.330	1.734	2.101	2.552	2.878	3.610	3.922
19	0.000	0.688	0.861	1.066	1.328	1.729	2.093	2.539	2.861	3.579	3.883
20	0.000	0.687	0.860	1.064	1.325	1.725	2.086	2.528	2.845	3.552	3.850
21	0.000	0.686	0.859	1.063	1.323	1.721	2.080	2.518	2.831	3.527	3.819
22	0.000	0.686	0.858	1.061	1.321	1.717	2.074	2.508	2.819	3.505	3.792
23	0.000	0.685	0.858	1.060	1.319	1.714	2.069	2.500	2.807	3.485	3.768
24	0.000	0.685	0.857	1.059	1.318	1.711	2.064	2.492	2.797	3.467	3.745
25	0.000	0.684	0.856	1.058	1.316	1.708	2.060	2.485	2.787	3.450	3.725
26	0.000	0.684	0.856	1.058	1.315	1.706	2.056	2.479	2.779	3.435	3.707
27	0.000	0.684	0.855	1.057	1.314	1.703	2.052	2.473	2.771	3.421	3.690
28	0.000	0.683	0.855	1.056	1.313	1.701	2.048	2.467	2.763	3.408	3.674
29	0.000	0.683	0.854	1.055	1.311	1.699	2.045	2.462	2.756	3.396	3.659
30	0.000	0.683	0.854	1.055	1.310	1.697	2.042	2.457	2.750	3.385	3.646
40	0.000	0.681	0.851	1.050	1.303	1.684	2.021	2.423	2.704	3.307	3.551
60	0.000	0.679	0.848	1.045	1.296	1.671	2.000	2.390	2.660	3.232	3.460
80	0.000	0.678	0.846	1.043	1.292	1.664	1.990	2.374	2.639	3.195	3.416
100	0.000	0.677	0.845	1.042	1.290	1.660	1.984	2.364	2.626	3.174	3.390
1000	0.000	0.675	0.842	1.037	1.282	1.646	1.962	2.330	2.581	3.098	3.300
z	0.000	0.674	0.842	1.036	1.282	1.645	1.960	2.326	2.576	3.090	3.291
	0%	50%	60%	70%	80%	90%	95%	98%	99%	99.8%	99.9%
	Confidence Level										

ICC EVALUATION SERVICE

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ACCEPTANCE CRITERIA FOR POST-INSTALLED ADHESIVE ANCHORS IN CONCRETE ELEMENTS

AC308

Approved November 2009

Effective November 1, 2009

Previously approved June 2009, October 2008, August 2008, May 2008, February 2008, January 2008, October 2007, June 2007, February 2007, June 2006

PREFACE

Evaluation reports issued by ICC Evaluation Service, Inc. (ICC-ES), are based upon performance features of the International family of codes and other widely adopted code families, including the Uniform Codes, the BOCA National Codes, and the SBCCI Standard Codes. Section 104.11 of the *International Building Code*® reads as follows:

> The provisions of this code are not intended to prevent the installation of any materials or to prohibit any design or method of construction not specifically prescribed by this code, provided that any such alternative has been approved. An alternative material, design or method of construction shall be approved where the building official finds that the proposed design is satisfactory and complies with the intent of the provisions of this code, and that the material, method or work offered is, for the purpose intended, at least the equivalent of that prescribed in this code in quality, strength, effectiveness, fire resistance, durability and safety.

Similar provisions are contained in the Uniform Codes, the National Codes, and the Standard Codes.

This acceptance criteria has been issued to provide all interested parties with guidelines for demonstrating compliance with performance features of the applicable code(s) referenced in the acceptance criteria. The criteria was developed and adopted following public hearings conducted by the ICC-ES Evaluation Committee, and is effective on the date shown above. All reports issued or reissued on or after the effective date must comply with this criteria, while reports issued prior to this date may be in compliance with this criteria or with the previous edition. If the criteria is an updated version from the previous edition, a solid vertical line (|) in the margin within the criteria indicates a technical change, addition, or deletion from the previous edition. A deletion indicator (→) is provided in the margin where a paragraph has been deleted if the deletion involved a technical change. This criteria may be further revised as the need dictates.

ICC-ES may consider alternate criteria, provided the report applicant submits valid data demonstrating that the alternate criteria are at least equivalent to the criteria set forth in this document, and otherwise demonstrate compliance with the performance features of the codes. Notwithstanding that a product, material, or type or method of construction meets the requirements of the criteria set forth in this document, or that it can be demonstrated that valid alternate criteria are equivalent to the criteria in this document and otherwise demonstrate compliance with the performance features of the codes, ICC-ES retains the right to refuse to issue or renew an evaluation report, if the product, material, or type or method of construction is such that either unusual care with its installation or use must be exercised for satisfactory performance, or if malfunctioning is apt to cause unreasonable property damage or personal injury or sickness relative to the benefits to be achieved by the use of the product, material, or type or method of construction.

Acceptance criteria are developed for use solely by ICC-ES for purposes of issuing ICC-ES evaluation reports.

ACCEPTANCE CRITERIA FOR POST-INSTALLED ADHESIVE ANCHORS IN CONCRETE ELEMENTS (AC308)

1.0 INTRODUCTION

1.1 Purpose: The purpose of this acceptance criteria is to establish requirements for post-installed adhesive anchors in concrete elements to be recognized in an ICC Evaluation Service, Inc. (ICC-ES), evaluation report under the 2009 *International Building Code*® (2009 IBC), 2006 *International Building Code*® (2006 IBC), the 2009 *International Residential Code*® (2009 IRC), 2006 *International Residential Code*® (2006 IRC), and the 1997 *Uniform Building Code*™ (UBC). Bases of recognition are IBC Section 104.11, IRC Section R104.11, BNBC Section 106.4, SBC Section 103.7 and UBC Section 104.2.8.

The reason for the development of this criteria is to allow for recognition of the use of adhesive anchors in concrete, since the prescriptive requirements of Chapter 19 of the IBC and Chapter 19 of the UBC do not include requirements for establishing the structural capacities of adhesive anchors used to create connections between structural concrete and attachments.

1.2 Scope: Anchors recognized under this criteria are alternatives to anchors permitted by Section 1913 of the IBC and Section 1923 of the UBC. The anchors recognized in this criteria may also be used where an engineered design is permitted in accordance with Section R301.1.2 of the IRC.

1.3 Codes and Referenced Standards: Where standards are referenced in this criteria, these standards shall be applied consistently with the code upon which compliance is based. Standards editions listed in this section apply to all codes. Where standards editions are not listed in this section, Table 1 summarizes the specific date applicable to each code.

1.3.1 2009 *International Building Code*® (2009 IBC), International Code Council.

1.3.2 2009 *International Residential Code*® (2009 IRC), International Code Council.

1.3.3 2006 *International Building Code*® (2006 IBC), International Code Council.

1.3.4 2006 *International Residential Code*® (2006 IRC), International Code Council.

1.3.5 1997 *Uniform Building Code*™ (UBC).

1.3.6 ACI 318, Building Code Requirements for Structural Concrete, American Concrete Institute.

1.3.7 ACI 211.1-91 (2002), Standard Practice for Selecting Proportions for Normal, Heavyweight and Mass Concrete, American Concrete Institute.

1.3.8 ASTM A 153, Standard Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware, ASTM International.

1.3.9 ASTM A 193/A 193 M-06a, Standard Specification for Alloy-Steel and Stainless Steel Bolting Materials for High Temperature or High Pressure Service and Other Special Purpose Applications, ASTM International.

1.3.10 ASTM A 490-04a, Standard Specification for Heat-Treated Steel Structural Bolts, 150 ksi Minimum Tensile Strength, ASTM International.

1.3.11 ANSI B 212.15-1994, American National Standard for Cutting Tools – Carbide Tipped Masonry Drills and Blanks for Carbide-Tipped Masonry Drills, American National Standards Institute.

1.3.12 ASTM B 695, Standard Specification for Coatings of Zinc Mechanically Deposited on Iron and Steel, ASTM International.

1.3.13 ASTM C 31, Standard Practice for Making and Curing Concrete Test Specimens in the Field, ASTM International.

1.3.14 ASTM C 33-03, Standard Specification for Concrete Aggregates, ASTM International.

1.3.15 ASTM C 39, Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens, ASTM International.

1.3.16 ASTM C 42, Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete, ASTM International.

1.3.17 ASTM C 150, Standard Specification for Portland Cement, ASTM International.

1.3.18 ASTM C 330, Standard Specification for Lightweight Aggregates for Structural Concrete, ASTM International.

1.3.19 ASTM C 882-05, Standard Test Method for Bond Strength of Epoxy-Resin Systems Used with Concrete by Slant Shear, ASTM International.

1.3.20 ASTM D 1875-03, Standard Test Method for Density of Adhesives in Fluid Form, ASTM International.

1.3.21 ASTM D 2471-99, Standard Test Method for Gel Time and Peak Exothermic Temperature of Reacting Thermosetting Resins, ASTM International.

1.3.22 ASTM D 2556-93a(2005), Standard Test Method for Apparent Viscosity of Adhesives Having Shear-Rate-Dependent Flow Properties, ASTM International.

1.3.23 ASTM E 119, Standard Test Methods for Fire Tests of Building Construction and Materials, ASTM International.

1.3.24 ASTM E 488-96(2003), Standard Test Method for Strength of Anchors in Concrete and Masonry Elements, ASTM International.

1.3.25 ASTM E 1252-98(2002), Standard Practice for General Techniques for Obtaining Infrared Spectra for Qualitative Analysis, ASTM International.

1.3.26 ASTM E 1512-93, Standard Test Methods for Testing Bond Performance of Adhesive-Bonded Anchors, ASTM International.

1.3.27 ASTM F 606-05, Standard Test Methods for Determining the Mechanical Properties of Externally and Internally Threaded Fasteners, Washers, and Rivets, ASTM International.

1.3.28 ASTM F 1080-93(2002), Standard Test Method for Determining the Consistency of Viscous Liquids Using a Consistometer, ASTM International.

1.3.29 EB001, Design and Control of Concrete Mixtures, 14th edition, 2002, Portland Cement Association.

1.4 Definitions: Definitions are presented in Section 2.1 of Annex A.

1.5 Notations: Notations are presented in Section 2.2 of Annex A.

2.0 BASIC INFORMATION

2.1 General: The following information shall be submitted:

2.1.1 Product Description: Anchors shall be described as to:

2.1.1.1 Generic or trade name.

2.1.1.2 Manufacturer's catalog number.

2.1.1.3 Adhesive name.

2.1.1.4 Adhesive packaging.

2.1.1.5 Basic Materials:

2.1.1.5.1 Steel Anchoring Materials: The bar, bolt, or threaded rod specifications shall be described. The description shall include protective coatings and compliance with an appropriate national standard, including physical properties, i.e., tensile strength and hardness.

2.1.1.5.2 Adhesive Components: The components shall be described as to the packaging system, mixing system, mixing ratios, gel time, setting time, storage information and shelf life.

2.1.1.6 Material Properties:

2.1.1.6.1 Steel:

2.1.1.6.1.1 Proprietary Steel Anchor Elements: Proprietary steel anchor elements for which recognition is sought shall be tested for compliance with an appropriate national standard for verification of physical properties.

2.1.1.6.1.2 Elongation and Reduction of Area: For both standard specification and proprietary steel anchor elements, elongation and reduction of area shall be determined according to a recognized standard and reported on the data sheet (Chapter 12 of Annex A). 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 in the evaluation report described as brittle.

2.1.1.6.2 Adhesive: For the adhesive used in the anchor tests, the components shall be tested in accordance with Section 6.3 of Annex A to establish a standard fingerprint for comparison with future production during the required quality control inspections. For quality control procedures, refer to Section 5.0 of this criteria.

2.1.2 Installation Instructions: Manufacturer's published instructions for installation, application, curing and design, including allowable loads, shall be submitted.

2.1.3 Packaging and Identification: A description shall be provided of the method of packaging and field identification of the adhesive anchor components. Identification provisions shall include information described in Section 6.4 of Annex A.

2.2 Testing Laboratories: Testing laboratories shall comply with Section 2.0 of the ICC-ES Acceptance Criteria for Test Reports (AC85) and Section 4.2 of the ICC-ES Rules of Procedure for Evaluation Reports.

2.3 Test Reports: Test reports shall include information specified in AC85 and Section 12.3 of Annex A.

2.4 Product Sampling: Sampling of the products for tests under this criteria shall comply with Section 3.1 of AC85.

2.5 Data Analysis: The documents containing analysis of data shall be sealed by a registered design professional.

3.0 TEST AND PERFORMANCE REQUIREMENTS

3.1 Testing Requirements: Testing requirements shall be in accordance with Section 4.0 of Annex A.

3.2 Test Specimens, Installation, General Test Procedures: Test specimens, test members, test anchor installation and general testing procedures shall be in accordance with Section 5.0 of Annex A. Where recognition in lightweight concrete is desired, all tests shall be conducted in lightweight concrete in accordance with Section 5.2 of Annex A. Use of the adjustment factors in ACI 318 Section D.3.4 in conjunction with testing in normal weight concrete is not permitted.

3.3 Assessment: Assessment of test results and other data shall be in accordance with Section 11.0 of Annex A.

3.4 Design: Anchor design shall be in accordance with Section 3.0 of Annex A.

4.0 TEST METHODS

4.1 Test Procedures: Test procedures shall be in accordance with Sections 6.0, 8.0, 9.0 and 10.0 of Annex A, based on requirements set forth in Section 4.0 of Annex A.

4.2 Legacy Test Data: Legacy test data done before January 1, 2006, in accordance with the ICC-ES Acceptance Criteria for Adhesive Anchors in Concrete and Masonry Elements (AC58), may be used to fulfill portions of this acceptance criteria in accordance with Supplement 1 to Annex A.

5.0 EVALUATION REPORT RECOGNITION

5.1 Quality Control During Manufacture: Quality control during manufacture of products shall comply with Sections 14.1 and 14.2 of Annex A.

5.2 Jobsite Quality Control: Jobsite quality control shall comply with Sections 14.3 and 14.4 of Annex A.

5.3 Product Modifications: Modified products and products produced at other locations previously evaluated shall be considered as set forth in Section 14.5 of Annex A.

6.0 EVALUATION REPORT

The evaluation report shall include the following:

6.1 Information and statements set forth in Section 12.4 of Annex A.

6.2 Basic information required by Section 2.1, including product description, installation procedures, and packaging and identification information.

6.3 Exposure: When anchors are recognized for exterior exposure or damp environments, evidence of durability shall be submitted. The steel shall be corrosion-resistant, stainless, or zinc-coated steel. The zinc-coating shall be either hot-dipped in accordance with ASTM A 153 Class C or D or mechanically deposited in accordance with ASTM B 695 with a Class 65 coating having a minimum thickness of 2.1 mils (0.053 mm). Other corrosion-resistant coatings shall be demonstrated through tests to be equivalent to the coatings previously described. In addition, the corrosion-resistant materials shall be tested for conformance to the specified standards.

6.4 Treated Wood: Steel anchoring materials in contact with preservative-treated and fire-retardant-treated wood shall be of zinc-coated steel or stainless steel. The coating weights for zinc-coated steel shall be in accordance with ASTM A 153.

6.5 Special Inspection: All adhesive anchors shall be installed with special inspection. The evaluation report shall include applicable information as called for in Sections 14.3 and 14.4 of Annex A.

6.6 The minimum allowable concrete member thickness shall be specified in the evaluation report, and shall be no less than $2h_{ef}$, unless other values are substantiated by testing. ■

TABLE 1—APPLICABLE EDITIONS OF REFERENCED STANDARDS

REFERENCED STANDARD	STANDARD EDITION	
	2009 IBC	2006 IBC
ACI 318	2008	2005
ACI 355	2007	2004
ASTM A 153	2005	2003
ASTM B 695	2004	2000
ASTM C 31	2006	1998
ASTM C 39	2005	2003
ASTM C 42	2004	2003
ASTM C 150	2007	2004
ASTM C 330	2005	2004
ASTM E 119	2007	2000

ANNEX A
QUALIFICATION OF POST-INSTALLED ADHESIVE ANCHORS IN CONCRETE

Synopsis: This Acceptance Criteria prescribes testing programs, evaluation requirements and design requirements for post-installed adhesive anchors intended for use in concrete. Testing, assessment, and design criteria are provided for adhesive anchors and torque-controlled adhesive anchors intended for various conditions of use including cracked concrete, seismic loading, aggressive environments and reduced and elevated temperatures.

Keywords: anchors, concrete; cracked concrete; adhesive anchors; torque-controlled adhesive anchors, post-installed anchors

Table of Contents:

1.0 INTRODUCTION

1.1 Purpose:

1.1.1 The purpose of this acceptance criteria is to establish testing programs and evaluation requirements for recognition of adhesive anchors in ICC Evaluation Service, Inc. (ICC-ES), evaluation reports under the 2009 *International Building Code*®, 2009 *International Residential Code*®, *2006 International Building Code®,* 2006 *International Residential Code*®, and the *1997 Uniform Building Code™*. Bases of recognition are IBC Section 104.11 and UBC Section 104.2.8.

1.2 Scope:

1.2.1 This criteria applies to adhesive anchors and torque-controlled adhesive anchors used to resist loads in cracked and uncracked normal- and lightweight concrete. It includes assessment of load capacity, reliability, service conditions, design procedures, and quality control. Special inspection is required during anchor installation as noted in Sections 11.24 and 14.3. Modifications to the strength design requirements of ACI 318 Appendix D as required to facilitate the design of adhesive anchors are provided in Section 3.0. Table 1.1 provides an overview of the criteria scope. Qualification of anchors exclusively for short-term loads is beyond the scope of this criteria.

Table 1.1 - Overview of anchor systems covered by this criteria

Anchor Type	Embedded part	Assessment Criteria		Design
Adhesive anchor	Steel bar with deformations or threads; reinforcing bar	Use in uncracked concrete only	Table 4.1	ACI 318 as modified by Section 3.0
		Use in cracked and uncracked concrete	Table 4.2	
Torque-controlled adhesive anchor	Round steel element with deformations designed to generate expansion forces	Bond/slip force verified	Table 4.3	ACI 318
		Bond/slip force not verified	Table 4.4	

1.2.2 Dimensional restrictions: This criteria applies exclusively to anchors conforming to the following dimensional parameters:

1.2.2.1 The anchor element diameter shall not be less than 1/4 in. (6 mm).

1.2.2.2 The anchor element shall be installed in a drilled hole that is approximately cylindrical with diameter $d_o \leq 1.5d$. See Section 5.5 for drill bit or core bit requirements.

1.2.2.3 The minimum embedment h_{ef} for anchorage design of adhesive anchors having diameter d shall be not be less than the values in Table 1.2 or 1.3:

TABLE 1.2—MINIMUM EMBEDMENT, IMPERIAL UNITS

d (inch)	≤ $^3/_8$	$^1/_2$	$^5/_8$	$^3/_4$	≥ 1
$h_{ef,min}$ (inches)	$2^3/_8$	$2^3/_4$	$3^1/_8$	$3^1/_2$	4d

TABLE 1.3—MINIMUM EMBEDMENT, SI UNITS

d (mm)	≤ 10	12	16	20	≥ 24
$h_{ef,\,min}$	60	70	80	90	4d

Minimum embedment depths lesser than those shown in Tables 1.2 or 1.3 shall be permitted where sufficient tests (minimum five specimens per diameter) have been conducted at the minimum member thickness with quadruple anchor groups in accordance with ASTM E 488. The mean peak load from the group tests at a given diameter shall not be less than 3.6 (0.9 × 4) times the mean peak load established for a single anchor at the same concrete compressive strength.

In no case shall the minimum embedment depth be taken as less than the minimum of 1.5 inches (40 mm) and 4*d*.

1.2.2.4 The maximum embedment h_{ef} of adhesive anchors having diameter d shall not exceed $20d$.

1.2.3 Other restrictions:

1.2.3.1 The concrete strength f_c for calculation purposes shall be limited to 2,500 psi ≤ f_c ≤ 8,000 psi (17 MPa ≤ f_c ≤ 55 MPa).

1.2.3.2 The tensile strength of anchor elements, f_{ut}, shall be ≤ 145,000 psi (100 MPa) unless separate investigations relating to susceptibility to hydrogen embrittlement and high and low-cycle fatigue are conducted.

1.2.3.3 Anchor elements fabricated from metals other than steel shall be permitted provided that they can be shown to possess mechanical properties suitable for structural applications and are otherwise assessed in accordance with the provisions of this criteria.

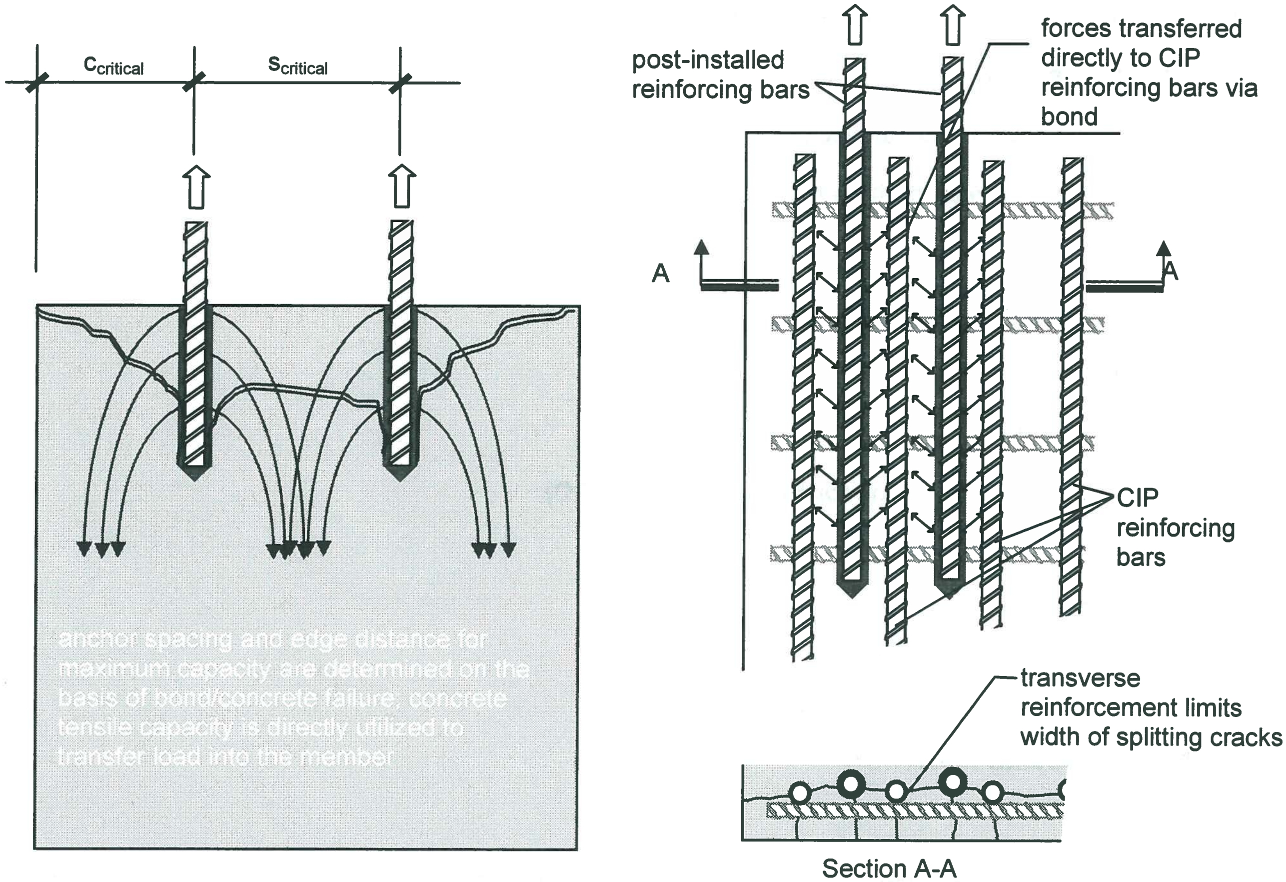
1.2.4 Exclusions: The following cases are not addressed by this criteria:

1.2.4.1 The assessment or design of anchors for high-cycle fatigue.

1.2.4.2 The assessment of bulk adhesive systems mixed in open containers.

1.2.4.3 The assessment or design of attachments affixed to the concrete surface with adhesive compounds.

1.2.4.4 In general, this criteria is intended to address the assessment and use of adhesive anchors for cases where anchor design theory applies (see Fig. 1.1a). It is not intended to address the assessment or design of post-installed reinforcing bars proportioned according to the concepts of reinforcement development (Fig. 1.1b).



a) Reinforcing dowels designed using anchor theory as addressed by this criteria

b) Post-installed reinforcement designed as a lap splice (not covered by this criteria)

Fig. 1.1 – Examples of post-installed reinforcing bars proportioned with anchor theory and with concepts of reinforcement development and splicing

1.3 Referenced Standards:

1.3.1 Codes:

1.3.1.1 2009 *International Building Code*® (2009 IBC)

1.3.1.2 2009 *International Residential Code*® (2009 IRC)

1.3.1.3 2006 *International Building Code*® (2006 IBC)

1.3.1.4 2006 *International Residential Code*® (2006 IRC)

1.3.1.5 1997 Uniform Building Code™ (UBC)

1.3.2 ICC Evaluation Service (ICC-ES):

1.3.2.1 AC10 Quality Documentation

1.3.2.2 AC85 Test Reports

1.3.2.3 AC193 Mechanical Anchors in Concrete Elements

1.3.2.4 Rules of Procedure for Evaluation Reports

1.3.3 ASTM International:

1.3.3.1 ASTM E 488-96 (Reapproved 2003)

1.3.4 American Concrete Institute (ACI)

1.3.4.1 ACI 318-08

1.3.4.2 ACI 318-05

1.3.4.3 ACI 355.2-07

1.3.4.4 ACI 355.2-04

1.3.5 International Organization for Standardization (ISO)

1.3.5.1 ISO 17020: 1998

1.3.5.2 ISO 17025: 2005

1.3.5.3 EN ISO 6988:1994

2.0 DEFINITIONS AND NOTATION

2.1 Definitions:

2.1.1 Adhesive anchor – A device for transferring tension and shear loads to structural concrete, consisting of an anchor element embedded with an adhesive compound in a cylindrical hole drilled in hardened concrete.

2.1.2 Adhesive compound – Any reactive adhesive comprised of chemical compounds (components) that react and cure when blended together. The adhesive compound may be formulated from organic polymer compounds, inorganic cementitious mortars or combination of organic and inorganic compounds. Organic adhesive materials include but are not limited to epoxies, polyurethanes, polyesters, methyl methacrylates and vinyl esters.

2.1.3 Aggressive exposure condition – Any anchor environmental exposure that may be characterized as equivalent to that produced by exposure of the adhesive compound to high alkalinity (pH ~ 13) and a high sulfur dioxide concentration (~ 0.7%).

2.1.4 Anchor category – An assigned rating that corresponds to a specific strength reduction factor, ϕ, for concrete failure modes associated with anchors in tension. The anchor category is established based on the performance of the anchor in installation safety tests.

2.1.5 Anchor diameter – Nominal diameter of the anchor element. For internally-threaded sleeves, the anchor diameter shall be taken as the outside diameter of the sleeve.

2.1.6 Anchor element – The metallic component of the anchor system that is embedded in the concrete with the adhesive compound. Anchor elements may include steel bars or rods with deformations or threads, deformed reinforcing bars, or internally threaded steel sleeves with external deformations.

2.1.7 Anchor installation – Unless otherwise noted, the process defined by the manufacturer's printed installation instructions for installation of the subject anchor. Anchor installation parameters may include but are not limited to ambient air and concrete temperature at the time of installation, concrete type, strength and condition at the time of installation, hole drilling method, hole size, hole cleaning and preparation requirements, adhesive material conditioning, mixing and placement, anchor element installation and retention, gel and cure time restrictions and installer safety requirements.

2.1.8 Anchor system – An anchor product line for which the component materials, functioning principles and installation parameters are consistent. An anchor system may consist of several anchor diameters, each associated with a specific anchor embedment, or multiple embedments associated with each anchor diameter.

2.1.9 Bulk adhesives – Adhesive compound components supplied in industrial quantities (e.g., barrels or one- to five-gallon cans).

2.1.10 Capsule anchor system – Adhesive compound components for anchor applications packaged in a glass or foil capsule. The capsule diameter corresponds roughly to the nominal anchor diameter. The quantity of resin, hardener and aggregate component in each capsule is suitable for a single anchor application. Mixing of the components is achieved during anchor installation. The capsule is fragmented and becomes part of the hardened resin matrix.

2.1.11 Cartridge system – Adhesive compound components for anchor applications packaged in a dual chamber cartridge for use with either manually- or power-driven dispensers. Metering and mixing of the components occurs automatically as the adhesive is dispensed through a manifold and mixing nozzle system.

2.1.12 Characteristic value – Reference is made in the text to calculation of the characteristic value and the 5% fractile. For the purposes of this criteria, these are interchangeable terms. The characteristic value is determined in accordance with Section 11.2. See also 5% fractile.

2.1.13 Concrete batch – A mixture of cement, aggregate, water and admixtures prepared and placed at a specific time and cured in a specific manner.

2.1.14 Concrete breakout failure – Failure of the anchor in an unconfined tension test characterized by the formation of a conical fracture surface originating at or near the embedded end of the anchor element and projecting to the surface of the concrete test member.

2.1.15 Cracked concrete – For the purposes of this criteria, a test member with an approximately uniform crack width over the depth of the concrete test member.

2.1.16 Cure time – The elapsed time after mixing of the adhesive material components to a state of hardening of the adhesive material in the drilled hole corresponding to the mechanical properties and resistances established via the conduct of tests described in this criteria.

2.1.17 Gel time – The elapsed time after mixing of the adhesive material components to onset of significant chemical reaction as characterized by an increase in viscosity. Mechanical disturbance of the chemical reaction after the gel time has elapsed and before the attainment of full cure as defined by the cure time is likely to result in impairment of adhesive material mechanical properties.

2.1.18 Hairline crack – The condition of a crack in an unloaded test member. Crack closure in cracked concrete test members is facilitated by tension forces in the longitudinal reinforcing steel in the test member. Following unloading of the test member, a residual crack width on the order of 0.002 in. (0.05 mm) will typically remain. The residual crack width associated with a hairline crack may be influenced by the presence of anchors installed in the crack path and by the crack width cycling history of the test member.

2.1.19 Independent Testing and Evaluation Agency (ITEA) – Laboratory accredited in conformance with Section 13.0 having responsibility for the testing and assessment of an anchor product in accordance with this criteria.

2.1.20 Manufacturer's published installation instructions – Printed instructions for the correct installation of the anchor under all covered installation conditions as supplied in the product packaging. Manufacturer's printed installation instructions shall be clear, concise, and easy to understand. In particular, the use of pictorial representation of procedures and processes is encouraged. All relevant steps shall be shown; in particular, modifications to the installation process to accommodate non-standard conditions (overhead installations, installation under damp or low temperature conditions, etc.) shall be clearly denoted where relevant.

2.1.21 Primary testing laboratory – See **Independent Testing and Evaluation Agency**.

2.1.22 Pullout failure – Failure of the anchor characterized by the withdrawal of the anchor element (threaded rod, reinforcing bars, etc.) from the concrete without rupture of the embedded part and without extraction of a full-depth conical breakout surface. The formation of limited-depth conical breakout surfaces shall be considered secondary to the pullout failure.

2.1.23 Small, medium and large diameters – The smallest, largest and intermediate diameters of the tested anchor system. The medium diameter shall be taken as the diameter most closely representing the arithmetic mean of the smallest and largest diameters.

2.1.24 Splitting failure – Failure of the anchor characterized by the formation of a planar crack in the concrete parallel to and extending through the axis of the anchor or anchors.

2.1.25 Standard temperature – 73° F ± 8° F (23° C ± 4° C)

2.1.26 Statistically equivalent – Two groups of test results shall be considered statistically equivalent if there are no significant differences between the means and between the standard deviations of the two groups. Such statistical equivalence shall be demonstrated using a one-sided Student's t-Test at a confidence level of 90%.

2.1.27 Steel failure – Failure of the anchor characterized by fracture of the anchor element.

2.1.28 Test member – A concrete element in which anchors are installed and tested.

2.1.29 Test series – A group of identical anchors tested under identical conditions. Identical conditions are diameter, length, embedment, spacing, edge distance, concrete density/weight, test member thickness, and concrete compressive strength.

2.1.30 Torque-controlled adhesive anchor – An adhesive anchor employing an anchor element designed to generate expansion forces in response to tension loading. Typically, the application of torque is employed to overcome the initial adhesion between anchor element and adhesive at a resultant tension load significantly less than that required to disrupt the adhesive-concrete bond. Displacement of the anchor rod relative to the adhesive in response to the tension load serves to generate expansion forces normal to the hole wall, further increasing the load transfer capability of the adhesive-concrete interface. Subsequent application of external tension loads beyond the initial preload results in further displacement of the anchor element and increased expansion forces. See Fig. 2.1.

2.1.31 Uncracked concrete – For the purposes of this criteria, a concrete test member having no noticeable cracks in the anchor vicinity prior to the installation and loading of anchors.

2.1.32 5% fractile – A value corresponding to a 5% probability of non-exceedence with a confidence of 90%, based on a noncentral Student's t-Distribution for which the population standard deviation is unknown. See also Characteristic value.

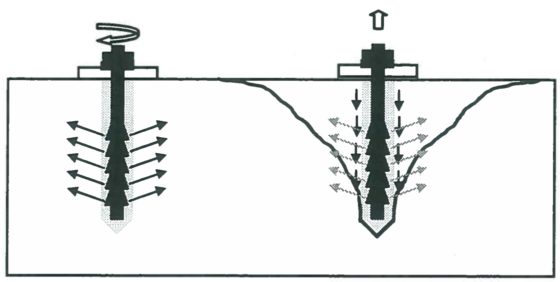


Fig. 2.1 – Schematic representation of a torque-controlled adhesive anchor

2.2 Notation:

2.2.1 Equations are provided in units of inches and pounds. For convenience, SI (metric) units are provided in parentheses where appropriate. Unless otherwise noted, values in SI units shall not be used in equations without conversion to units of inches and pounds.

A_{Na} = the projected area of the failure surface for the anchor or group of anchors in accordance with Section 3.0, in.^{2} (mm^2).

A_{Na0} = the projected area of the failure surface of a single anchor without the influence of proximate edges in accordance with Section 3.0, in.^{2} (mm^2).

A_{se} = effective cross sectional area of anchor, in.^{2} (mm^2).

$c_{cr,Na}$ = critical adhesive anchor edge distance for tension loading, i.e., the edge distance at which the anchor tension capacity is theoretically unaffected by the proximate edge in accordance with Section 3.0, in. (mm).

c_{min} = minimum anchor edge distance as required to prevent splitting during anchor installation, see Section 9.10, in. (mm).

d = nominal diameter of the anchor element, see Fig. 2.2, in. (mm).

d_o = nominal diameter of drilled hole in the concrete, see Fig. 2.2, in. (mm)

f'_c = specified concrete compressive strength in accordance with ACI 318, psi (MPa).

$f_{c,i}$ = concrete compressive strength as measured with standard cylinders for concrete of batch i or test member i, psi (MPa).

$f_{c,test,x}$ = concrete compressive strength corresponding to concrete used for test series x, psi (MPa)

f_{ut} = specified ultimate tensile strength of anchor steel, psi (MPa).

$f_{ut,test,x}$ = steel tensile strength corresponding to anchors used for test series x, psi (MPa).

f_y = specified yield strength of anchor steel, psi (MPa).

$F_{test,x}$ = test result from test series x, lb (N).

$\bar{F}_{test,x}$ = mean of test results from test series x, lb (N).

F_{test,x,f_c} = test result normalized to concrete strength f_c in accordance with Section 11.1.2, lb (N).

$F_{test,x,f_{ut}}$ = test result normalized to steel strength f_{ut} in accordance with Section 11.1.3, lb (N).

F_k = characteristic value (5% fractile), calculated according to Section 0, lb (N).

F_y = tension force corresponding to bolt yield in accordance with Eq. 11.29, lb (N).

h = thickness of test member in which an anchor is installed, measured perpendicular to the concrete surface, see Fig. 2.2, in. (mm).

h_{ef} = effective embedment depth, measured from the concrete surface to the deepest point on the anchor element at which bond to the concrete is established, see Fig. 2.2, in. (mm).

h_{min} = minimum member thickness specified by the anchor manufacturer and verified in accordance with Sections 11.7, 11.8, 11.18 and 11.19, in. (mm).

h_{sl} = slice thickness as measured immediately prior to punch testing in accordance with Section 9.8, in. (mm).

k_{cp} = effectiveness factor for calculation of concrete pryout capacity in accordance with Section 3.0.

k_{cr} = effectiveness factor for calculation of concrete breakout capacity in cracked concrete, see Section 11.4.7.

k_m = mean effectiveness factor in accordance with Section 11.4.7.2.

k_{uncr} = effectiveness factor for calculation of concrete breakout capacity in uncracked concrete, see Section 11.4.7.

K = tolerance factor corresponding to a 5% probability of non-exceedence with a confidence of 90%, derived from a noncentral t-distribution for which the population standard deviation is unknown.

n = number of replicates in a test series; number of tension loaded anchors in a group; exponent.

N = tension load or capacity, lb (N).

N_{cb} = nominal concrete strength of a single anchor in tension as limited by concrete cone breakout (upper bound on concrete strength), lb (N).

N_{cbg} = nominal concrete strength of a group of anchors in tension as limited by concrete cone breakout (upper bound on concrete strength), lb (N).

N_{a} = nominal strength of an adhesive anchor in tension as limited by bond/concrete failure in accordance with Section 3.0, lb (N).

N_{adh} = tension load corresponding to loss of adhesion between the adhesive and the concrete, lb (N).

$N_{adh,i,j}$ = adhesion force corresponding to test series i, test j.

N_{ag} = nominal strength of an adhesive anchor group loaded in tension as limited by bond/concrete failure in accordance with Section 3.0, lb (N).

N_{a0} = characteristic tension capacity of a single adhesive anchor in tension as limited by bond/concrete failure in accordance with Section 3.0, lb (N).

$\overline{N}_{bond,\phi}$ = mean tension force corresponding to loss of adhesion between the adhesive and the concrete for anchor diameter ϕ, lb (N).

$\overline{N}_{cure}$ = mean tension capacity corresponding to the manufacturer's published minimum cure time, lb (N).

$\overline{N}_{cure+24h}$ = mean tension capacity corresponding to the manufacturer's published minimum cure time plus 24 hours, lb (N).

N_{eq} = the maximum tension load to be applied in the simulated seismic tension test, lb (N).

$N_{eq,reduced}$ = a reduced maximum tension load at which the anchor successfully completes the simulated seismic tension test, see Section 11.21.1.2, lb (N).

N_{i} = the intermediate tension load to be applied in the simulated seismic tension test, lb (N).

$N_{i,reduced}$ = a reduced intermediate tension load at which the anchor successfully completes the simulated seismic tension test, see Section 11.21.1.2, lb (N).

N_{k} = characteristic tension capacity of an anchor (5 % fractile of test results) as determined in accordance with Section ~~0~~ 11.2, lb (N).

$N_{k,cure}$ = characteristic tension capacity corresponding to the manufacturer's published minimum cure time, lb (N).

$N_{k,cure+24h}$ = characteristic tension capacity corresponding to the manufacturer's published minimum cure time plus 24 hours, lb (N).

$N_{k,i}$ = characteristic tension capacity of an anchor in test member i or concrete batch i, lb (N).

$N_{k,bond,\phi}$ = characteristic tension force corresponding to loss of adhesion between the adhesive and the concrete for anchor diameter ϕ, lb (N).

$N_{k,lt}$ = characteristic tension capacity at long-term elevated temperature, lb (N).

$N_{k,o,i}$ = characteristic tension capacity of an anchor in reference test series i, lb (N).

$N_{k,p,nom,cr}$ = characteristic tension capacity corresponding to service-condition tests in low- and high-strength cracked concrete, lb (N).

$N_{k,p,nom,uncr}$ = characteristic tension capacity corresponding to service-condition tests in low- and high-strength uncracked concrete, lb (N).

$N_{k,p,seis}$ = seismic tension pull-out resistance of a torque-controlled adhesive anchor, lb (N).

$N_{k,r,i}$ = characteristic tension capacity of an anchor in reliability test series i, lb (N).

$N_{k,st}$ = characteristic tension capacity at short-term elevated temperature, lb (N).

$\bar{N}_{lt}$ = mean tension capacity of an anchor at long-term elevated temperature, lb (N).

N_m = the minimum tension load to be applied in the simulated seismic tension test, lb (N).

$N_{m,reduced}$ = a reduced minimum tension load at which the anchor successfully completes the simulated seismic tension test, see Section 11.21.1.2, lb (N).

$\bar{N}_{o,i}$ = mean tension capacity of an anchor in reference test series i, lb (N).

N_{origin} = tension load corresponding to origin of load displacement curve, lb (N).

N_p = characteristic tension pullout capacity of an anchor (5 % fractile of test results) as determined in accordance with Section ~~0~~ 11.2, lb (N).

$\bar{N}_{r,i}$ = mean tension capacity of an anchor in reliability test series i, lb (N).

N_{red} = reduced sustained load in a reliability test series as required to satisfy displacement criteria, lb (N).

$\bar{N}_{ref,f_c}$ = normalized mean ultimate tension load for round-robin tests, lb (N).

N_s = characteristic tension steel capacity of an anchor as determined in accordance with Section 0, lb (N).

$\bar{N}_{slip,\phi}$ = mean tension force corresponding to loss of adhesion between the anchor element and the adhesive for anchor diameter ϕ, lb (N).

$\bar{N}_{st}$ = mean tension capacity at short-term elevated temperature, lb (N).

$N_{sust,ft}$ = sustained tension load applied during freeze-thaw cycles, lb (N).

$N_{sust,lt}$ = sustained tension load applied at long-term test temperature, lb (N).

N_u = peak tension load measured in a tension test, lb (N).

$\bar{N}_{u,i}$ = mean ultimate tension load measured in a tension test in test series i or concrete batch i, lb (N).

$N_{u,i,j}$ = peak tension load measured in a tension test in test series or concrete batch i, test j, lb (N).

N_{u,i,f_c} = peak tension load measured in a tension test conducted in test series i or concrete batch i, normalized to concrete strength f_c, lb (N).

N_w = tension load applied to anchor during crack width cycling, lb (N).

N_1 = limiting load for uncontrolled slip of a torque-controlled adhesive anchor in accordance with Section 11.4.6.2, lb (N).

$N_{1,x}$ = load corresponding to uncontrolled slip of a torque-controlled adhesive anchor, lb (N).

$N_{95\%}$ = 95% fractile at 90% confidence of the induced tension force corresponding to $1.3\ T_{inst}$, lb (N).

$N_{95\%,slip,\phi}$ = 95% fractile at 90% confidence of the force corresponding to loss of adhesion between the anchor element and the adhesive for anchor diameter ϕ, lb (N).

$R_{allow,ASD}$ = allowable load for use in allowable stress design environments, lb (N).

R_d = limiting design strength in tension (ϕN_n) or shear (ϕV_n) as calculated in accordance with ACI 318 Appendix D and this criteria, lb (N).

$s_{cr,Na}$ = critical adhesive anchor spacing for tension loading, i.e., the minimum spacing between adjacent loaded anchors at which the tension capacity of each anchor is theoretically unaffected by the presence of the adjacent loaded anchor as determined in accordance with Section 3.0, in. (mm).

s_{min} = minimum anchor spacing as required to prevent splitting during anchor installation or tension loading, see Section 9.10, in. (mm).

$t_{service}$ = the intended anchor service life in accordance with Section 11.12.2, (hours).

T = applied torque in a test, ft-lb (N-m).

T_{inst} = specified tightening torque for setting or pretensioning of an anchor, according to the manufacturer's published installation instructions, ft-lb (N-m).

V = shear load or capacity, lb (N).

V_{cpg} = pryout strength of an adhesive anchor group loaded in shear in accordance with Section 3.0, lb (N).

V_{eq} = the maximum shear load to be applied in the simulated seismic shear test, lb (N).

$V_{eq,reduced}$ = a reduced maximum shear load at which the anchor successfully completes the simulated seismic shear test, see Section 11.22.1.2, lb (N).

V_i = the intermediate shear load to be applied in the simulated seismic shear test, lb (N).

$V_{i,reduced}$ = a reduced intermediate shear load at which the anchor successfully completes the simulated seismic shear test, see Section 11.22.1.2, lb (N).

V_m = the minimum shear load to be applied in the simulated seismic shear test, lb (N).

$V_{m,reduced}$ = a reduced minimum shear load at which the anchor successfully completes the simulated seismic shear test, see Section 11.22.1.2, lb (N).

V_s = characteristic shear capacity corresponding to steel failure, lb (N).

$V_{s,seis}$ = seismic shear capacity as governed by steel failure, lb (N).

α = the ratio of reliability or service-condition test results to reference tension test results calculated in accordance with Section 11.3.3.

α_{adh} = the ratio of the load at loss of adhesion to the ultimate load calculated in accordance with Section 11.3.4.

α_{ASD} = factor for conversion from strength design to allowable stress design in accordance with Section 3.0.

α_{cat3} = additional reduction factor for anchor category 3 in accordance with Section 11.3.6.4.

α_{conc} = normalization factor for regional variations in concrete in accordance with Eq. 11.5.

α_{cov} = reduction factor for larger coefficients of variation in accordance with Section 11.3.2.

α_{dur} = reduction factor for durability in accordance with Eq. 11.36.

α_{lt} = reduction factor for maximum long-term temperature in accordance with Eq. 11.33.

$\alpha_{N,seis}$ = reduction factor for seismic tension loading in accordance with Eq. 11.37.

α_{ρ} = reduction factor for reliability tests in accordance with Eq. 11.26.

α_{req} = controlling value for reliability tests and service-condition tests where calculation of α is required.

$\alpha_{req,cat3}$ = α_{req} for anchor category 3 for corresponding installation safety test in accordance with Table 11.4 or Table 11.5.

α_{setup} = reduction factor for service condition tests performed as confined tests in accordance with Section 11.3.5.

α_{slip} = reduction factor for uncontrolled slip in accordance with Section 11.4.6.2.

α_{st} = reduction factor for maximum short-term temperature in accordance with Eq. 11.34.

$\alpha_{V,seis}$ = reduction factor for seismic shear loading in accordance with Eq, 11.38.

β = reduction factor associated with Eq. 11.12 (adhesive anchors) and Eq. 11.23 (torque-controlled adhesive anchors).

β_1 = statistical correction factor for the determination of the mean effectiveness factor k_m in accordance with Eq. 11.22.

Δ = anchor displacement as measured in a test, in. (mm).

Δh = thickness of concrete member beyond h_{ef}, see Fig. 2.2, in. (mm).

Δ_{origin} = displacement at origin of load displacement curve discounting initial play in the test apparatus, in. (mm).

Δ_{lim} = displacement corresponding to N_{adh} or N_{slip} (mm).

$\Delta_{0.3}$ = displacement at $N = 0.3N_u$, in. (mm).

$\Delta_{service}$ = extrapolated estimate of the total displacement over the anchor intended service life, in. (mm).

$\bar{\Delta}_{service}$ = mean of the extrapolated estimates of the total displacement over the anchor intended service life, in. (mm).

$\Delta_{t=0}$ = initial displacement under sustained load, in. (mm).

$\Delta(t)$ = displacement at time t under sustained load, in. (mm).

Δw = required change in crack width (additional to the initial hairline crack width as measured after anchor installation), in. (mm).

ϕ = strength reduction factor for concrete failure modes associated with tension loading corresponding to the anchor category established in accordance with Section 11.0.

$v_{test,x}$ = coefficient of variation of the population sample corresponding to test series x, %.

$\bar{\tau}_{dur,i}$ = mean bond strength corresponding to durability tests with test member i or concrete batch i stored in different media according to Eq. 9.1, psi (MPa).

τ_i = calculated bond strength corresponding to peak load in a tension test, psi (MPa).

$\bar{\tau}_i$ = mean bond strength corresponding to test series i or concrete batch i, psi (MPa).

$\tau_{k,cr}$ = characteristic bond strength in cracked concrete adjusted for variations in concrete batches and reduced in accordance with Eq. 11.12, psi (MPa).

$\tau_{k,i}$ = characteristic bond strength corresponding to tension tests in test member i or concrete batch i, psi (MPa).

$\tau_{k,o,i}$ = characteristic bond strength corresponding to reference tension tests in test member i or concrete batch i, psi (MPa).

$\tau_{k,max,cr}$ = limiting bond strength corresponding to concrete breakout in cracked concrete, psi (MPa).

$\tau_{k,max,uncr}$ = limiting bond strength corresponding to concrete breakout in uncracked concrete, psi (MPa).

$\tau_{k,nom,cr}$ = nominal characteristic tension bond strength in cracked concrete, psi (MPa).

$\tau_{k,nom,uncr}$ = nominal characteristic tension bond strength in uncracked concrete, psi (MPa).

$\tau_{k,seis}$ = seismic tension bond resistance calculated in accordance with Eq. 11.13, psi (MPa).

$\tau_{k,uncr}$ = characteristic bond strength in uncracked concrete adjusted for variations in concrete batches and reduced in accordance with Eq. 11.12, psi (MPa).

$\overline{\tau}_{o,i}$ = mean bond strength corresponding to a reference tension test in test member i or concrete batch i. psi (MPa).

$\overline{\tau}_{ref,f_c}$ = normalized mean bond strength corresponding to round-robin tests, psi (MPa).

τ_u = bond strength, psi (MPa).

$\overline{\tau}_{u,f_c}$ = normalized mean bond strength, psi (MPa).

$\overline{\tau}_{u,i}$ = mean bond strength corresponding to tension tests in test member i or concrete batch, psi (MPa).

$\psi_{ec,Na}$ = factor for eccentrically loaded adhesive anchor groups in accordance with Section 3.0.

$\psi_{g,Na}$ = factor for the influence of the failure surface of a group of adhesive anchors in accordance with Section 3.0.

$\psi_{p,Na}$ = factor for critical edge distance in accordance with Section 3.0.

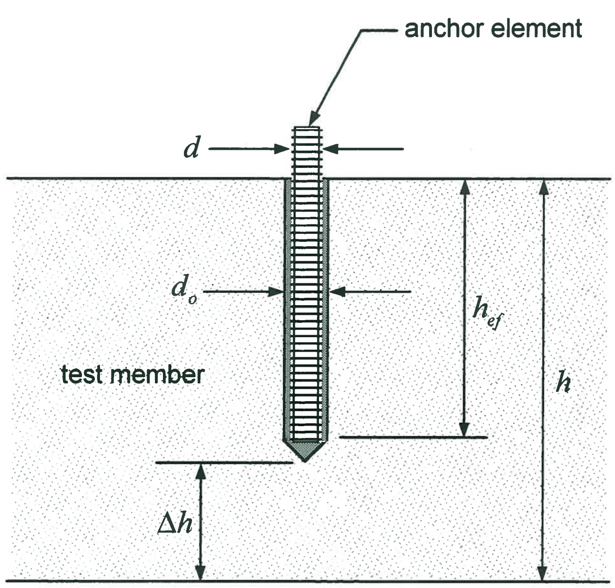


Fig. 2.2 – Definition of dimensional parameters

3.0 DESIGN REQUIREMENTS

3.1 General:

3.1.1 Allowable stress design (working stress design) of adhesive anchors and torque-controlled adhesive anchors shall be in conformance with Section 3.2 of this criteria.

3.1.2 Strength design of adhesive anchors and torque-controlled adhesive anchors shall be in conformance with Section 3.3 of this criteria.

3.2 *Optional Allowable Stress Design (ASD) Information (Optional):*

3.2.1 *Strength design values determined in accordance with ACI 318 Appendix D with amendments in Section 3.3 of this criteria may be converted to values suitable for use with allowable stress design load combinations. Such guidance of conversions shall be in accordance with the following:*

3.2.1.1 *General: For anchors designed using load combinations in accordance with IBC Section 1605.3 (Allowable Stress Design) allowable loads shall be established using the equations below.*

$$T_{allowable,ASD} = \frac{\phi N_n}{\alpha} \quad \text{Eq. 3.1}$$

And

$$V_{allowable,ASD} = \frac{\phi V_n}{\alpha} \quad \text{Eq. 3.2}$$

Where

$T_{allowable,ASD}$ = *Allowable tension load (lbf or kN)*

$V_{allowable,ASD}$ = *Allowable shear load (lbf or kN)*

ϕN_n = *Lowest design strength of an anchor or anchor group in tension as determined in accordance with ACI 318 Appendix D with amendments in Section 3.3 of this criteria, 2009 IBC Sections 1908.1.9 and 1908.1.10 and 2006 IBC Section 1908.1.16.*

ϕV_n = *Lowest design strength of an anchor or anchor group in shear as determined in accordance with ACI 318 Appendix D with amendments in Section 3.3 of this criteria and 2009 IBC Sections 1908.1.9 and 1908.1.10 and 2006 Section 1908.1.16.*

α = *Conversion factor calculated as a weighted average of the load factors for the controlling load combination. In addition, α shall include all applicable factors to account for non-ductile failure modes and required over-strength.*

Interaction shall be calculated in accordance with ACI 318 Appendix D Section D.7 as follows:

For shear loads $V \leq 0.2V_{allowable,\ ASD}$, the full allowable load in tension shall be permitted.

For tension loads $T \leq 0.2T_{allowable,\ ASD}$, the full allowable load in shear shall be permitted.

For all other cases:

$$\frac{T}{T_{allowable}} + \frac{V}{V_{allowable}} \leq 1.2$$

3.2.1.2 *A single table for illustration of calculated Allowable Stress Design (ASD) values for each anchor diameter and embedment considering the following design assumptions (listed as footnotes to the table shall be included in the evaluation report:*

1. *Single anchor with static tension load only*
2. *Vertical downward installation direction*
3. *Inspection regimen = __ (determined by manufacturer)*
4. *Installation temperature = __(determined by manufacturer)*
5. *Long term temperature = __ (determined by manufacturer)*
6. *Short term temperature = __ (determined by manufacturer)*
7. *Dry hole condition (carbide drilled hole)*
8. *Embedment =* $h_{ef,min}$ *(for each diameter)*
9. *Concrete determined to remain uncracked for the life of the anchorage*
10. *Load combination from ACI 318 Section 9.2 (no seismic loading)*
11. *30% dead load and 70% live load, controlling load combination 1.2 D + 1.6L*
12. *Calculation of weighted average for* $\alpha = 0.3*1.2 + 0.7*1.6 = 1.48$
13. f'_c *= 2,500 psi (normal weight concrete)*
14. $c_{a1} = c_{a2} \geq c_{ac}$
15. $h \geq h_{min}$

Table Title: "Example Allowable Stress Design Values for Illustrative Purposes"

3.2.2 For load combinations including earthquake in regions designated as Seismic Design Categories, C, D, E, or F, the value R_d in *Eq. 3.1 or Eq. 3.2* shall be multiplied by a factor 0.75 in accordance with ACI 318 Section D.3.3.3.

3.3 Strength design - amendments to ACI 318:

3.3.1 Adhesive anchors: This section provides amendments to ACI 318-05 Appendix D (ACI 318) as required for the strength design of adhesive anchors. In conformance with ACI 318-05, all equations are expressed in inch-pound units.

3.3.1.1 Add or revise Sections D.4.1.2, D.4.1.4, D.5.2.9, D.5.2.10, D.5.3.7, D.5.3.8, D.5.3.9, D.5.3.10, D.5.3.11, D.5.3.12, D.5.3.13, D.5.3.14, D.6.3.2 and D.8.8 to ACI 318 as follows:

D.4.1.2 – In Eq. (*D-1*) and (*D-2*), ϕN_n and ϕV_n are the lowest design strengths determined from all appropriate failure modes. ϕN_n is the lowest design strength in tension of an anchor or group of anchors as determined from consideration of ϕN_{nsa}, either ϕN_a or ϕN_{ag} and either ϕN_{cb} or ϕN_{cbg}. ϕV_n is the lowest design strength in shear of an anchor or a group of anchors as determined from consideration of: ϕV_{sa}, either ϕV_{cb} or ϕV_{cbg}, and either ϕV_{cp} or ϕV_{cpg}. For adhesive anchors subjected to tension resulting from sustained loading, see D.4.1.4.

D.4.1.4 – For adhesive anchors subjected to tension resulting from sustained loading, a supplementary design analysis shall be performed using Eq. (D-1) whereby N_{ua} is determined from the sustained load alone, e.g., the dead load and that portion of the live load acting that may be considered as sustained and ϕN_n is determined as follow:

D.4.1.4.1 – For single anchors, $\phi N_n = 0.75\phi N_{a0}$

D.4.1.4.2 – For anchor groups, Eq. (D-1) shall be satisfied by taking $\phi N_n = 0.75\phi N_{a0}$ for that anchor in an anchor group that resists the highest tension load.

D.4.1.4.3 – Where shear loads act concurrently with the sustained tension load, interaction of tension and shear shall be analyzed in accordance with D.4.1.3

2006 IBC: D.5.2.9; 2009 IBC: D.5.2.10 – The limiting concrete strength of adhesive anchors in tension shall be calculated in accordance with_D.5.2.1 to D.5.2.9 under the 2009 IBC or D.5.2.1 to D. 5.2.8 under the 2006 IBC where the value of k to be used in Eq. (D-7) shall be

$k = 17$ — *where analysis indicates cracking at service load levels in the anchor vicinity (cracked concrete)*

$k = 24$ — *where analysis indicates no cracking $(f_t < f_r)$ at service load levels in the anchor vicinity (uncracked concrete)*

The value of k shall be permitted to be increased to $k = 24$ (cracked concrete) and $k = 30$ (uncracked concrete) based on the results of tests in accordance with AC308.

D.5.3.7 – The nominal strength of a single adhesive anchor N_a or group of adhesive anchors N_{ag} in tension shall not exceed

(a) for a single anchor

$$N_a = \frac{A_{Na}}{A_{na0}} \cdot \psi_{ed,Na} \cdot \psi_{p,Na} \cdot N_{a0} \qquad \text{(D-16a)}$$

(b) for a group of anchors

$$N_{ag} = \frac{A_{Na}}{A_{Na0}} \cdot \psi_{ed,Na} \cdot \psi_{g,Na} \cdot \psi_{ec,Na} \cdot \psi_{p,Na} \cdot N_{a0} \qquad \text{(D-16b)}$$

Where

A_{Na} *is the projected area of the failure surface for the anchor or group of anchors that shall be approximated as the base of the rectilinear geometrical figure that results from projecting the failure surface outward a distance $c_{cr,Na}$ from the centerline of the single anchor, or in the case of a group of anchors, from a line through a row of adjacent anchors. A_{Na} shall not* exceed nA_{Na0} where n is the number of anchors in tension in the group. (Refer to ACI 318 Figures RD.5.2.1a and RD.5.2.1b and replace the terms $1.5h_{ef}$ and $3.0h_{ef}$ with $c_{cr,Na}$ and $s_{cr,Na}$, respectively.)

A_{Na0} is the projected area of the failure surface of a single anchor without the influence of proximate edges in accordance with Eq. (D-16c):

$$A_{Na0} = \left(s_{cr,Na}\right)^2 \qquad \text{(D-16c)}$$

with

$s_{cr,Na}$ = as given by Eq. (D-16d)

D.5.3.8 – The critical spacing $s_{cr,Na}$ and critical edge distance $c_{cr,Na}$ shall be calculated as follows:

$$s_{cr,Na} = 20 \cdot d \cdot \sqrt{\frac{\tau_{k,uncr}}{1,450}} \leq 3 \cdot h_{ef} \qquad \text{(D-16d)}$$

$$c_{cr,Na} = \frac{s_{cr,Na}}{2} \qquad \text{(D-16e)}$$

D.5.3.9 – The basic strength of a single adhesive anchor in tension in cracked concrete shall not exceed

$$N_{a0} = \tau_{k,cr} \cdot \pi \cdot d \cdot h_{ef} \qquad \text{(D-16f)}$$

where

$\tau_{k,cr}$ is the characteristic bond strength in cracked concrete having strength

f'_c evaluated from tests in accordance with AC308.

D.5.3.10 – The modification factor for the influence of the failure surface of a group of adhesive anchors is

$$\psi_{g,Na} = \psi_{g,Na0} + \left[\left(\frac{s}{s_{cr,Na}}\right)^{0.5} \cdot \left(1 - \psi_{g,Na0}\right)\right] \qquad \text{(D-16g)}$$

where

$$\psi_{g,Na0} = \sqrt{n} - \left[\left(\sqrt{n} - 1\right) \cdot \left(\frac{\tau_{k,cr}}{\tau_{k,max,cr}}\right)^{1.5}\right] \geq 1.0 \qquad \text{(D-16h)}$$

n is the number of tension loaded adhesive anchors in a group.

$$\tau_{k,max,cr} = \frac{k_{c,cr}}{\pi \cdot d}\sqrt{h_{ef} \cdot f'_c} \quad \text{(D-16i)}$$

whereby the value of $k_{c,cr}$ shall be permitted to be increased to a maximum value based on the results of tests in cracked concrete in accordance with AC308.

D.5.3.11 – The modification factor for eccentrically loaded adhesive anchor groups is

$$\psi_{ec,Na} = \frac{1}{1 + \frac{2e'_N}{s_{cr,Na}}} \leq 1.0 \quad \text{(D-16j)}$$

Eq. (D-16j) is valid for $e'_N \leq \frac{s}{2}$

If the loading on an anchor group is such that only some anchors are in tension, only those anchors that are in tension shall be considered when determining the eccentricity e'_N *for use in Eq. (D-16j).*
In the case where eccentric loading exists about two orthogonal axes, the modification factor $\psi_{ec,Na}$ *shall be computed for each axis individually and the product of these factors used as* $\psi_{ec,Na}$ *in Eq. (D-16b).*

D.5.3.12 – The modification factor for edge effects for single adhesive anchors or anchor groups loaded in tension is

$$\psi_{ed,Na} = 1.0 \text{ when } c_{a,min} \geq c_{cr,Na} \quad \text{(D-16l)}$$

or

$$\psi_{ed,Na} = \left(0.7 + 0.3 \cdot \frac{c_{a,min}}{c_{cr,Na}}\right) \leq 1.0 \quad \text{when } c_{a,min} < c_{cr,Na} \quad \text{(D-16m)}$$

D.5.3.13 – When an adhesive anchor or a group of adhesive anchors is located in a region of a concrete member where analysis indicates no cracking at service load levels, the nominal strength N_a *or* N_{ag} *of a single adhesive anchor or a group of adhesive anchors shall be calculated according to Eq. (D-16a) and Eq. (D-16b) with* $\tau_{k,uncr}$ *substituted for* $\tau_{k,cr}$ *in the calculation of the basic strength* N_{a0} *in accordance with Eq. (D-16f).*

$\tau_{k,uncr}$ *shall be established based on tests in accordance with AC308. The factor* $\psi_{g,Na0}$ *shall be calculated in accordance with Eq. (D-16h) whereby the value of* $\tau_{k,max,uncr}$ *shall be calculated in accordance with Eq. (D-16n) and substituted for* $\tau_{k,max,cr}$ *in Eq. (D-16h).*

$$\tau_{k,max,uncr} = \frac{k_{c,uncr}}{\pi \cdot d}\sqrt{h_{ef} \cdot f'_c} \qquad (D\text{-}16n)$$

D.5.3.14 – When an adhesive anchor or a group of adhesive anchors is located in a region of a concrete member where analysis indicates no cracking at service load levels, the modification factor $\psi_{p,Na}$ shall be taken as

$$\psi_{p,Na} = 1.0 \qquad \text{when} \qquad c_{a,min} \geq c_{ac} \qquad (D\text{-}16o)$$

$$\psi_{p,Na} = \frac{max|c_{a,min}; c_{cr,Na}|}{c_{ac}} \qquad \text{when} \qquad c_{a,min} < c_{ac} \qquad (D\text{-}16p)$$

where

c_{ac} *shall be determined by testing in accordance with AC308.*

For all other cases, $\psi_{p,Na} = 1.0$.

D.6.3.2 – The nominal pryout strength of a single adhesive anchor V_{cp} or group of adhesive anchors V_{cpg} shall not exceed

(a) for a single adhesive anchor

$$V_{cp} = min|k_{cp} \cdot N_a; k_{cp} \cdot N_{cb}| \qquad (D\text{-}30a)$$

(b) for a group of adhesive anchors

$$V_{cpg} = min|k_{cp} \cdot N_{ag}; k_{cp} \cdot N_{cbg}| \qquad (D\text{-}30b)$$

Where

$k_{cp} = 1.0$ *for h_{ef} < 2.5 in. (64 mm)*

$k_{cp} = 2.0$ *for $h_{ef} \geq$ 2.5 in. (64 mm)*

N_a *is calculated in accordance with Eq. (D-16a)*

N_{ag} *is calculated in accordance with Eq. (D-16b)*

N_{cb}, N_{cbg} *are determined in accordance with D.5.2.1 to D.5.2.9*

D.8.8 – For adhesive anchors that will remain untorqued, the minimum edge distance shall be based on minimum cover requirements for reinforcement in 7.7. For adhesive anchors that will be torqued, the minimum edge distance and spacing shall be taken as $6d_o$ and $5d_o$, respectively, unless otherwise determined in accordance with AC308.

3.3.2 Torque-controlled adhesive anchors: This section provides amendments to ACI 318 Appendix D (ACI 318) as required for the strength design of torque-controlled adhesive anchors.

3.3.2.1 Add Section D.5.3.7 to ACI 318 as follows:

D.5.3.7 – For torque-controlled adhesive anchors, the value of N_p shall be based on the 5 percent fractile of tests performed and evaluated in accordance with AC308.

D.8.7 – For torque-controlled adhesive anchors the minimum edge distance shall be taken as $8d_o$ unless otherwise determined by test in accordance with AC308.

4.0 GENERAL TESTING REQUIREMENTS

4.1 Test organization:

4.1.1 Qualification of adhesive anchors in accordance with this criteria requires four basic types of tests:

1. Identification tests to evaluate anchor compliance with manufacturer's specifications (Section 6.0);
2. Reference tests to obtain baseline values for the evaluation of reliability and service-condition test results (Section 7.0);
3. Reliability tests to assess anchor sensitivity to adverse installation conditions and long-term use (Section 8.0); and
4. Service-condition tests to establish anchor performance under expected service conditions (Section 9.0).

4.1.2 In addition, the following testing may take place as follows:

4.1.2.1 Round-robin tests for adhesive anchors to establish the effects of regional variations in concrete on anchor behavior (see Section 10.1).

4.1.2.2 Optional tests to verify the minimum member thickness (see Section 10.2).

4.1.2.3 Supplementary tests for multiple anchor element types (see Sections 4.5 and 4.6).

4.1.2.4 Supplementary tests for multiple drilling methods (see Section 0).

4.2 Variables and options:

4.2.1 The assessment of a given anchor system in accordance with this criteria will involve consideration of the following system variables:

1. Hole cleaning procedures specified in the anchor manufacturer's published installation instructions. Options typically include vacuuming, evacuation with forced air and brushing. Quantification of the

number, order and duration of cleaning operations and description of the equipment to be used is required.

2. Drilling methods explicitly permitted for the installation (e.g., rotary hammer drill with carbide bit, core drill, rock drill).
3. Orientations relative to gravity permitted for the installation (down-hole, overhead, horizontal).
4. Embedment depth range permitted for a given anchor diameter.
5. Anchor element types included in the system, including material types (carbon, stainless), strengths and geometries (threaded rod, reinforcing bar, internally threaded inserts).

4.2.2 Available options to be considered for the assessment are shown schematically in Fig. 4.1.

4.3 Test requirements for adhesive anchors:

4.3.1 Test requirements for adhesive anchors to be assessed to resist static loads and wind loads in uncracked concrete conditions are defined in Table 4.1.

4.3.2 Test requirements for adhesive anchors to be assessed to resist static loads, wind loads and seismic loads in both cracked and uncracked concrete conditions are defined in Table 4.2.

4.3.3 Optional tests:

4.3.3.1 Service condition seismic simulation tests.

4.3.3.1.1 Qualification to resist seismic loads shall be based on the fulfillment of the test requirements defined in Table 4.2, including the optional seismic simulation tests.

4.3.3.2 Service condition tests for environmental exposure (freeze/thaw, aggressive exposure conditions).

4.3.3.3 Installation safety tests to assess the effect of the presence of moisture, standing water in the drilled hole or a submerged condition when hole cleaning is conducted in accordance with manufacturer's published installation instructions.

4.3.3.4 Tests to verify the minimum member thickness.

4.4 Test requirements for torque-controlled adhesive anchors:

4.4.1 Test requirements for torque-controlled adhesive anchors to resist static loads in both cracked and uncracked concrete are defined in either Table 4.3 or Table 4.4. Optional tests for qualification to resist seismic loads are also included in these tables. Use of Table 4.3 is conditional on the establishment of the bond/slip force relationship for the anchor in accordance with Section 11.4.1.1. If this relationship is not established, testing shall be in accordance with Table 4.4.

4.4.1.1 Bond/slip force relationship:

4.4.1.1.1 Torque-controlled adhesive anchors transmit tension loads to the concrete in a manner similar to mechanical expansion anchors. In order for this to occur, the adhesion between the anchor element and the adhesive must be broken without destroying the adhesion between the adhesive and the concrete. The shape and finish of the anchor element and the mechanical properties of the adhesive produce the necessary relationship between the slip force (force required to break the adhesion between the anchor rod and the adhesive) and the bond force (force required to overcome the adhesion between the adhesive and the concrete in the absence of any expansion or normal force). The shape of the anchor element is chosen so that subsequent displacement of the element relative to the adhesive generates expansion forces, which in turn generate friction between the adhesive and the concrete.

4.4.2 Optional tests:

4.4.2.1 Service condition seismic simulation tests.

4.4.2.1.1 Qualification to resist seismic loads shall be based on the fulfillment of the test requirements defined in Table 4.3 or Table 4.4, including the optional seismic simulation tests.

4.4.2.2 Service condition tests for environmental exposure (freeze/thaw, aggressive exposure conditions).

4.4.2.3 Installation safety tests to assess the effect of the presence of moisture, standing water in the drilled hole or submerged conditions when hole cleaning is conducted in accordance with manufacturer's published installation instructions.

4.4.2.4 Reliability tests to verify the bond/slip force relationship are given in Table 4.3, Test Nos. 10a and 10b. Confirmation of the bond/slip force relationship in accordance with Section 11.4.1.1 is required if a torque-controlled adhesive anchor system is to be evaluated with Table 4.3.

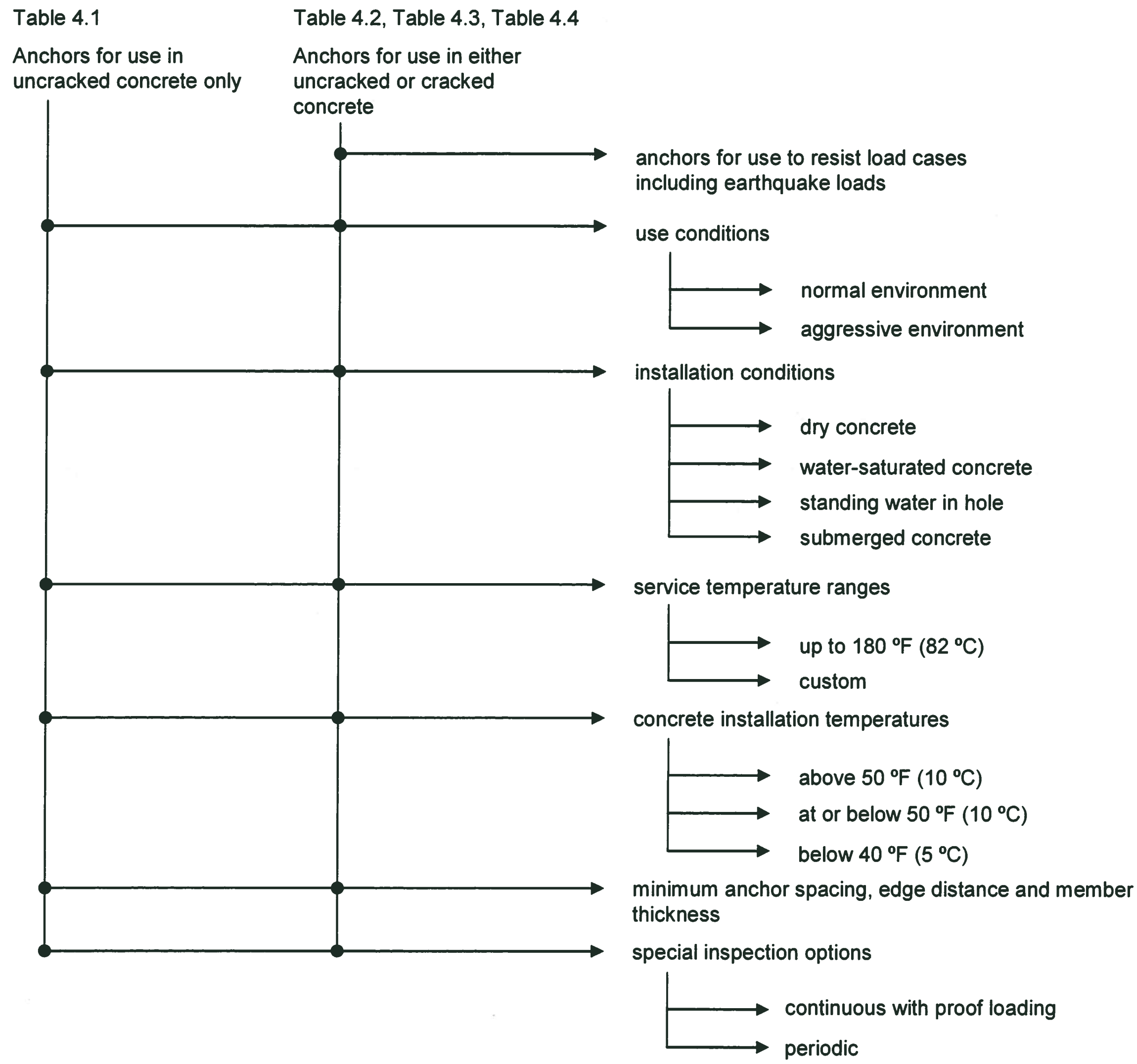


Fig. 4.1 – Available options

Table 4.1 – Test program for evaluating adhesive anchor systems for use in uncracked concrete

Testing				Assessment				No. of tests
Test no.	Test ref.	Purpose	Test parameters	α_{req}	Load & displ.	f_c	h_{ef} [d]	n_{min}
Reference tests								
1a	§7.0	Reference tension in low-strength concrete	Tension, confined, single anchor away from edges	NA	NA	low	min max	5 per batch
1b	§7.0	Reference tension in high-strength concrete	Tension, confined, single anchor away from edges	NA	NA	high	min	5 per batch
Reliability tests								
2a	§8.5	Sensitivity to hole cleaning, dry substrate	Tension, confined, single anchor away from edges	§11.3.6	§11.3.2 §11.3.4	low	max	5[a]
2b	§8.6	Sensitivity to hole cleaning, installation in saturated concrete[h]	Tension, confined, single anchor away from edges	§11.3.6	§11.3.2 §11.3.4	low	max	5[a]
2c	§8.7	Sensitivity to hole cleaning, installation in a water-filled hole[h]	Tension, confined, single anchor away from edges	§11.3.6	§11.3.2 §11.3.4	low	max	5[a]
2d	§8.8	Sensitivity to hole cleaning, installation in submerged concrete[h]	Tension, confined, single anchor away from edges	§11.3.6	§11.3.2 §11.3.4	low	max	5[a]
2e	§8.9	Sensitivity to mixing effort	Tension, confined, single anchor away from edges	§11.3.6	§11.3.2 §11.3.4	low	max	5[b]
2f	§8.11	Sensitivity to installation in saturated concrete[h,k]	Tension, confined, single anchor away from edges	§11.3.6	§11.3.2 §11.3.4	low	max	5[a]
2g	§8.12	Sensitivity to installation in a water-filled hole[h]	Tension, confined, single anchor away from edges	§11.3.6	§11.3.2 §11.3.4	low	max	5[a]
2h	§8.13	Sensitivity to installation in submerged concrete[h]	Tension, confined, single anchor away from edges	§11.3.6	§11.3.2 §11.3.4	low	max	5[a]
3	§8.17	Sensitivity to freeze/thaw conditions[h]	Sustained tension, residual capacity, confined test	0.90	§11.3.2 §11.3.4 §11.11	high	min	5[b]
4	§8.18	Sensitivity to sustained load	Sustained tension, residual capacity, confined test	0.90	§11.3.2 §11.3.4 §11.12	low	min	5[b]
5	§8.19	Sensitivity to installation direction[h]	Tension, confined, single anchor away from edges	0.90	§11.3.2 §11.3.4 §11.13	low	max	5[m]

Table 4.1 – Test program for evaluating adhesive anchor systems for use in uncracked concrete

Testing				Assessment				No. of tests
Test no.	Test ref.	Purpose	Test parameters	α_{req}	Load & displ.	f_c	h_{ef} [d]	n_{min}
6	§8.20	Torque test[f]	Application of torque, confined, single anchor away from edges	NA	§11.9	high	min	5[e]
Service-condition tests								
7a	§9.4	Tension in low-strength concrete	Tension, unconfined, single anchor away from edges[l]	NA	§11.3.2 §11.3.4 §11.3.5	low	min max	5[e]
7b	§9.4	Tension in high-strength concrete[j]	Tension, unconfined, single anchor away from edges[l]	NA	§11.3.2 §11.3.4 §11.3.5	high	min	5[e]
8a	§9.5	Tension at elevated temperatures	Tension, confined, single anchor away from edges	NA	§11.3.2 §11.3.4 §11.14	low	min	5[b]
8b	§9.6	Tension at decreased installation temperature[h]	Tension, confined single anchor away from edges	NA	§11.3.2 §11.3.4 §11.15	low	min	5[b]
8c	§9.7	Curing time at standard temperature	Tension, confined single anchor away from edges	NA	§11.3.2 §11.3.4 §11.16	low	min	5[b]
9a	§9.8	Resistance to alkalinity	Slice tests	NA	§11.17	low	NA	10[b]
9b	§9.8	Resistance to sulfur[h]	Slice tests	NA	§11.17	low	NA	10[b]
10	§9.9	Edge distance in corner condition to develop full capacity	Tension, unconfined single anchor in corner with proximate edges[g]	NA	§11.18	low	min max	4[e]
11	§9.10	Minimum spacing and edge distance to preclude splitting	High installation tension (torque or unconfined tension) two anchors near an edge[g]	NA	§11.19	low	min	5[e]
12	§9.11	Shear capacity of steel element having a non-uniform cross section[c]	Shear – single anchor away from edges	NA	§11.20	low	min	5[e]
Supplemental tests								
13	§10.1	Round-robin tests	Tension, confined and unconfined single anchor away from edges	NA	§11.3.1	low[i]	$7d$	5[b]
14	§10.2	Minimum member thickness[h]	Installation tests[g]	NA	§11.7	low	max	10[e]

Notes for Table 4.1:

a. Test small, medium and large diameters.

b. Test the ½ in. (M12) diameter or the smallest nominal diameter if it is larger than $^1/_2$ in. (M12).

c. Test is required only for anchors having a cross sectional area, within five anchor diameters of the shear failure plane, that is less than that of a threaded bolt having the same nominal diameter as the anchor.

d. Where the manufacturer's printed installation instructions specify multiple embedment depths for a single anchor diameter, test the anchor at the minimum or maximum embedment depth as noted, whereby $h_{ef,max}/h_{ef,min} \leq 5.0$. See also Section 5.7.2.

e. Test all diameters.

f. See also Section 4.5 for multiple anchor element types.

g. Minimum member thickness h_{min} shall be used for these tests.

h. Optional test.

i. Test in concrete having a measured strength of 3,000 psi ± 500 psi (20.7 MPa ± 3.3 MPa) at time of testing.

j. Tests are optional if test results of Test 1b can be shown to be statistically equivalent to or greater than the results of Test 1a. If Test 7b is not conducted, calculation of anchor tension resistance shall be limited to f'_c = 2,500 psi (17.2 MPa) regardless of the in-situ concrete strength.

k. Test 2f may be omitted if Test 2g is performed.

l. Alternatively, tests may be performed as confined tests.

m. For overhead and horizontal orientations, test the largest diameter for which recognition is sought.

Table 4.2– Test program for evaluating adhesive anchor systems for use in cracked and uncracked concrete

Testing				Crack width Δw	Assessment				No. of tests
Test no.	Test ref.	Purpose	Test parameters	inches (mm)	α_{req}	Load & displ.	f_c	h_{ef} [d]	n_{min}
Reference tests									
1a	§7.0	Reference tension in low-strength concrete	Tension, confined, single anchor away from edges	NA	NA	NA	low	min max	5 per batch
1b	§7.0	Reference tension in low-strength, cracked concrete	Tension, confined, single anchor away from edges	0.012 (0.3)	NA	NA	low	min	5 per batch
1c	§7.0	Reference tension in high-strength concrete	Tension, confined, single anchor away from edges	NA	NA	NA	high	min	5 per batch
1d	§7.0	Reference tension in high-strength, cracked concrete [j]	Tension, confined, single anchor away from edges	0.012 (0.3)	NA	NA	high	min	5 per batch
Reliability tests									
2a	§8.5	Sensitivity to hole cleaning, dry substrate	Tension, confined, single anchor away from edges	NA	§11.3.6	§11.3.2 §11.3.4	low	max	5[a]
2b	§8.6	Sensitivity to hole cleaning, installation in saturated concrete[h]	Tension, confined, single anchor away from edges	NA	§11.3.6	§11.3.2 §11.3.4	low	max	5[a]
2c	§8.7	Sensitivity to hole cleaning, installation in a water-filled hole[h]	Tension, confined, single anchor away from edges	NA	§11.3.6	§11.3.2 §11.3.4	low	max	5[a]
2d	§8.8	Sensitivity to hole cleaning, installation in submerged concrete[h]	Tension, confined, single anchor away from edges	NA	§11.3.6	§11.3.2 §11.3.4	low	max	5[a]
2e	§8.9	Sensitivity to mixing effort	Tension, confined, single anchor away from edges	NA	§11.3.6	§11.3.2 §11.3.4	low	max	5[b]
2f	§8.11	Sensitivity to installation in saturated concrete[h,k]	Tension, confined, single anchor away from edges	NA	§11.3.6	§11.3.2 §11.3.4	low	max	5[a]
2g	§8.12	Sensitivity to installation in a water-filled hole[h]	Tension, confined, single anchor away from edges	NA	§11.3.6	§11.3.2 §11.3.4	low	max	5[a]
2h	§8.13	Sensitivity to installation in submerged concrete[h]	Tension, confined, single anchor away from edges	NA	§11.3.6	§11.3.2 §11.3.4	low	max	5[a]
3	§8.14	Sensitivity to crack width low-strength concrete	Tension, confined, single anchor away from edges	0.020 (0.5)	0.80	§11.3.2 §11.3.4	low	min	5[a]
4	§8.15	Sensitivity to crack width high strength concrete[j]	Tension, confined, single anchor away from edges	0.020 (0.5)	0.80	§11.3.2 §11.3.4	high	min	5[a]

Table 4.2– Test program for evaluating adhesive anchor systems for use in cracked and uncracked concrete

Testing				Crack width Δw	Assessment				No. of tests
Test no.	Test ref.	Purpose	Test parameters	inches (mm)	α_{req}	Load & displ.	f_c	h_{ef} [d]	n_{min}
5	§8.16	Sensitivity to crack width cycling	Sustained tension, single anchor away from edges, residual capacity, confined test	0.004-0.012 (0.1-0.3)	0.90	§11.3.2 §11.3.4 §11.10	low	min	5[e]
6	§8.17	Sensitivity to freeze/thaw conditions[h]	Sustained tension, residual capacity, confined test	NA	0.90	§11.3.2 §11.3.4 §11.11	high	min	5[b]
7	§8.18	Sensitivity to sustained load	Sustained tension, residual capacity, confined test	NA	0.90	§11.3.2 §11.3.4 §11.12	low	min	5[b]
8	§8.19	Sensitivity to installation direction[h]	Tension, confined, single anchor away from edges	NA	0.90	§11.3.2 §11.3.4 §11.13	low	max	5[n]
9	§8.20	Torque test[f]	Application of torque, confined, single anchor away from edges	NA	NA	§11.9	high	min	5[e]
Service-condition tests									
11a	§9.4	Tension in low-strength concrete	Tension, unconfined, single anchor away from edges[l]	NA	NA	§11.3.2 §11.3.4 §11.3.5	low	min max	5[e]
11b	§9.4	Tension in high-strength concrete[j]	Tension, unconfined, single anchor away from edges[l]	NA	NA	§11.3.2 §11.3.4 §11.3.5	high	min	5[e]
11c	§9.4	Tension in low-strength, cracked concrete	Tension, unconfined, single anchor away from edges[m]	0.012 (0.3)	NA	§11.3.2 §11.3.4 §11.3.5	low	min	5[e]
11d	§9.4	Tension in high-strength, cracked concrete[j]	Tension, unconfined, single anchor away from edges[m]	0.012 (0.3)	NA	§11.3.2 §11.3.4 §11.3.5	high	min	5[e]
12a	§9.5	Tension at elevated temperatures	Tension, confined single anchor away from edges	NA	NA	§11.3.2 §11.3.4 §11.14	low	min	5[b]
12b	§9.6	Tension at decreased installation temperature[h]	Tension, confined single anchor away from edges	NA	NA	§11.3.2 §11.3.4 §11.15	low	min	5[b]
12c	§9.7	Curing time at standard temperature	Tension, confined single anchor away from edges	NA	NA	§11.3.2 §11.3.4 §11.16	low	min	5[b]

Table 4.2– Test program for evaluating adhesive anchor systems for use in cracked and uncracked concrete

Testing				Crack width Δw	Assessment				No. of tests
Test no.	Test ref.	Purpose	Test parameters	inches (mm)	α_{req}	Load & displ.	f_c	h_{ef} [d]	n_{min}
13a	§9.8	Resistance to alkalinity	Slice tests	NA	NA	§11.17	low	NA	10[b]
13b	§9.8	Resistance to sulfur[h]	Slice tests	NA	NA	§11.17	low	NA	10[b]
14	§9.9	Edge distance in corner condition to develop full capacity	Tension, unconfined single anchor in corner with proximate edges[g]	NA	NA	§11.18	low	min max	4[e]
15	§9.10	Minimum spacing and edge distance to preclude splitting	High installation tension (torque or unconfined tension) two anchors near an edge[g]	NA	NA	§11.19	low	min	5[e]
16	§9.11	Shear capacity of anchor element having a non-uniform cross section[c]	Shear – single anchor away from edges	NA	NA	§11.20	low	min	5[e]
17	§9.12	Seismic tension[h]	Pulsating tension, single anchor away from edges	0.020 (0.5)	NA	§11.3.2 §11.3.4 §11.21	low	min max	5[e]
18	§9.13	Seismic shear[h]	Alternating shear, single anchor away from edges	0.020 (0.5)	NA	§11.22	low	min	5[a]
Supplemental tests									
19	§10.1	Round-robin tests	Tension, confined and unconfined, single anchor away from edges	NA	NA	§11.3.1	low[i]	$7d$	5[b]
20	§10.2	Minimum member thickness[h]	Installation tests[g]	NA	NA	§11.7	low	max	10[e]

Notes for Table 4.2:

a. Test small, medium and large diameters.

b. Test the ½ in. (M12) diameter or the smallest nominal diameter if it is larger than ½ in. (M12).

c. Test is required only for anchors having a cross sectional area, within five anchor diameters of the shear failure plane, that is less than that of a threaded bolt having the same nominal diameter as the anchor.

d. Where the manufacturer's printed installation instructions specify multiple embedment depths for a single anchor diameter, test the anchor at the minimum or maximum embedment depth as noted, whereby $h_{ef,max}/h_{ef,min} \leq 5.0$. See also Section 5.7.2.

e. Test all diameters.

f. See also Section 4.5 for multiple anchor element types.

g. Minimum member thickness h_{min} shall be used for these tests.

h. Optional test.

i. Test in concrete having a measured strength of 3,000 psi ± 500 psi (20.7 MPa ± 3.3 MPa) at time of testing.

Notes for Table 4.2:

j. Tests are optional if test results of Test 1c can be shown to be statistically equivalent to or greater than the results of Test 1a. If any of Tests 1d, 4, 11b, and 11d are not performed, calculation of anchor tension resistance shall be limited to f'_c = 2,500 psi (17.2 MPa) regardless of the in-situ concrete strength.

k. Test 2f may be omitted if Test 2g is performed.

l. Alternatively, tests may be performed as confined tests.

m. These tests shall be permitted to be supplemented by confined tests.

n. For overhead and horizontal orientations, test the largest diameter for which recognition is sought.

Table 4.3– Test program for evaluating torque-controlled adhesive anchor systems for use in cracked and uncracked concrete: Bond/slip force relationship confirmed in accordance with Section 11.4.1

Testing				Crack width Δw	Assessment				No. of tests
Test no.	Test ref.	Purpose	Test parameters	inches (mm)	α_{req}	Load & displ.	f_c	h_{ef} [d]	n_{min}
Reference tests									
1a	§7.0	Reference tension in low-strength concrete	Tension, confined, single anchor away from edges	NA	NA	NA	low	min max	5 per batch
1b	§7.0	Reference tension in high-strength concrete	Tension, confined, single anchor away from edges	NA	NA	NA	high	min	5 per batch
Reliability tests									
2a	§8.10	Sensitivity to reduced installation effort	Tension, unconfined, single anchor away from edges[j]	0.012 (0.3)	§11.4.5	§11.4.4 §11.4.6	low	max	5[a]
2b	§8.5	Sensitivity to hole cleaning, dry substrate	Tension, unconfined, single anchor away from edges[k]	0.012 (0.3)	§11.4.5	§11.4.4 §11.4.6	low	max	5[a]
2c	§8.6	Sensitivity to hole cleaning, installation in saturated concrete[h]	Tension, unconfined, single anchor away from edges[k]	0.012 (0.3)	§11.4.5	§11.4.4 §11.4.6	low	max	5[a]
2d	§8.7	Sensitivity to hole cleaning, installation in a water-filled hole[h]	Tension, unconfined, single anchor away from edges[k]	0.012 (0.3)	§11.4.5	§11.4.4 §11.4.6	low	max	5[a]
2e	§8.8	Sensitivity to hole cleaning, installation in submerged concrete[h]	Tension, unconfined, single anchor away from edges[k]	0.012 (0.3)	§11.4.5	§11.4.4 §11.4.6	low	max	5[a]
2f	§8.9	Sensitivity to mixing effort	Tension, unconfined single anchor away from edges[k]	0.012 (0.3)	§11.4.5	§11.4.4 §11.4.6	low	max	5[b]
3	§8.14	Sensitivity to crack width low-strength concrete	Tension, unconfined single anchor away from edges[k]	0.020 (0.5)	0.80	§11.4.4 §11.4.6	low	min	5[a]
4	§8.15	Sensitivity to crack width high strength concrete	Tension, unconfined single anchor away from edges[k]	0.020 (0.5)	0.80	§11.4.4 §11.4.6	high	min	5[a]
5	§8.16	Sensitivity to crack width cycling	Sustained tension single anchor away from edges residual capacity, unconfined test[k]	0.004-0.012 (0.1-0.3)	0.90	§11.4.4 §11.4.6 §11.10	low	min	5[e]
6	§8.17	Sensitivity to freeze/thaw conditions[h,m]	Sustained tension residual capacity, confined test[k]	NA	0.90	§11.4.4 §11.4.6 §11.11	high	min	5[b]
7	§8.18	Sensitivity to sustained load[m]	Sustained tension residual capacity, confined test[k]	NA	0.90	§11.4.4 §11.4.6 §11.12	low	min	5[b]

Table 4.3– Test program for evaluating torque-controlled adhesive anchor systems for use in cracked and uncracked concrete: Bond/slip force relationship confirmed in accordance with Section 11.4.1

Testing				Crack width Δw	Assessment				No. of tests
Test no.	Test ref.	Purpose	Test parameters	inches (mm)	α_{req}	Load & displ.	f_c	h_{ef} [d]	n_{min}
8	§8.19	Sensitivity to installation direction[h]	Tension, unconfined single anchor away from edges[k]	0.012 (0.3)	0.90	§11.4.4 §11.4.6 §11.13	low	max	5[n]
9	§8.20	Torque test	Application of torque, confined, single anchor away from edges[f]	NA	NA	§11.9	high	min	5[e]
10a	§8.21	Slip force test	Tension, confined, single anchor away from edges[i]	0.012 (0.3)	NA	§11.4.2	low	min	5[n]
10b	§8.22	Bond force test	Tension, confined, single anchor away from edges[i]	0.012 (0.3)			low	min	5[e]
Service-condition tests									
11a	§9.4	Tension in low-strength concrete	Tension, unconfined single anchor away from edges[k]	NA	NA	§11.4.4 §11.4.6	low	all	5[e]
11b	§9.4	Tension in high-strength concrete	Tension, unconfined single anchor away from edges[k]	NA	NA	§11.4.4 §11.4.6	high	all	5[e]
11c	§9.4	Tension in low-strength, cracked concrete	Tension, unconfined single anchor away from edges[k]	0.012 (0.3)	NA	§11.4.4 §11.4.6	low	all	5[e]
11d	§9.4	Tension in high-strength, cracked concrete	Tension, unconfined single anchor away from edges[k]	0.012 (0.3)	NA	§11.4.4 §11.4.6	high	all	5[e]
12a	§9.5	Tension at elevated temperatures	Tension, confined single anchor away from edges[k,l,m]	NA	NA	§11.4.4 §11.4.6 §11.14	low	min	5[b]
12b	§9.6	Tension at decreased installation temperature[h]	Tension, confined single anchor away from edges[k,l,m]	NA	NA	§11.4.4 §11.4.6 §11.15	low	min	5[b]
12c	§9.7	Curing time at standard temperature	Tension, confined single anchor away from edges[k,l,m]	NA	NA	§11.4.4 §11.4.6 §11.16	low	min	5[b]
13a	§9.8	Resistance to alkalinity	Slice tests[l,m]	NA	NA	§11.17	low	NA	10[b]
13b	§9.8	Resistance to sulfur[h]	Slice tests[l,m]	NA	NA	§11.17	low	NA	10[b]
14	§9.9	Edge distance in corner condition to develop full capacity	Tension, unconfined single anchor in corner with proximate edges[g,k]	NA	NA	§11.18	low	min max	4[e]

Table 4.3– Test program for evaluating torque-controlled adhesive anchor systems for use in cracked and uncracked concrete: Bond/slip force relationship confirmed in accordance with Section 11.4.1

Testing				Crack width Δw	Assessment				No. of tests
Test no.	Test ref.	Purpose	Test parameters	inches (mm)	α_{req}	Load & displ.	f_c	h_{ef} [d]	n_{min}
15	§9.10	Minimum spacing and edge distance to preclude splitting on loading	High installation tension (torque or direct) - two anchors near edge[g]	NA	NA	§11.19	low	min	5[e]
16	§9.11	Shear capacity of steel element having a non-uniform cross section[c]	Shear – single anchor away from edges[k]	NA	NA	§11.20	low	min	5[e]
17	§9.12	Seismic tension[h]	Pulsating tension, single anchor away from edges[k]	0.020 (0.5)	NA	§11.4.2 §11.4.6 §11.21	low	min max	5[e]
18	§9.13	Seismic shear[h]	Alternating shear, single anchor away from edges[k]	0.020 (0.5)	NA	§11.22	low	min	5[a]
Supplemental tests									
19	§10.2	Minimum member thickness[h]	Installation tests[g]	NA	NA	§11.8	low	Max	10[e]

Notes for Table 4.3:

a. Test small, medium and large diameters.

b. Test the ½ in. (M12) diameter or the smallest nominal diameter if it is larger than 1/2 in. (M12).

c. Test is required only for anchors having a cross sectional area, within five anchor diameters of the shear failure plane, that is less than that of a threaded bolt having the same nominal diameter as the anchor.

d. Where the manufacturer's printed installation instructions specify multiple embedment depths for a single anchor diameter, test the anchor at the minimum or maximum embedment depth as noted, whereby $h_{ef,max}/h_{ef,min} \leq 5.0$. See also Section 5.7.2.

e. Test all diameters.

f. This test confirms the value of T_{inst} to be used for the test program. As such, it should be conducted before performing other tests requiring application of torque.

g. Minimum member thickness h_{min} shall be used for these tests.

h. Optional test.

i. Anchors untorqued.

j. Install anchors with 50% of the recommended installation torque T_{inst}.

k. See Section 5.6.2.1.1 for torque requirements.

l. These tests shall be permitted to be performed with threaded steel rod substituted for the anchor element. In this case, reference tests must be performed with threaded steel rod as well.

m. If these tests have been previously been performed in accordance with Table 4.1 or Table 4.2 using the same adhesive as that employed for the torque-controlled adhesive anchor and the correct static load, they may be omitted here.

n. For overhead and horizontal orientations, test the largest diameter for which recognition is sought.

Table 4.4– Test program for evaluating torque-controlled adhesive anchor systems for use in cracked and uncracked concrete: Bond/slip force relationship unconfirmed

Testing				Crack width Δw	Assessment				No. of tests
Test no.	Test ref.	Purpose	Test parameters	inches (mm)	α_{req}	Load & displ.	f_c	h_{ef} [d]	n_{min}
Reference tests									
1a	§7.0	Reference tension in low-strength concrete	Tension, confined, single anchor away from edges	NA	NA	NA	low	min max	5 per batch
1b	§7.0	Reference tension in high-strength concrete	Tension, confined, single anchor away from edges	NA	NA	NA	high	min	5 per batch
Reliability tests									
2a	§8.10	Sensitivity to reduced installation effort	Tension, unconfined, single anchor away from edges[j]	0.012 (0.3)	§11.4.5	§11.4.4 §11.4.6	low	max	10[e]
2b	§8.5	Sensitivity to hole cleaning, dry substrate	Tension, unconfined, single anchor away from edges[k]	0.012 (0.3)	§11.4.5	§11.4.4 §11.4.6	low	max	10[e]
2c	§8.6	Sensitivity to installation in saturated concrete[h]	Tension, unconfined, single anchor away from edges[k]	0.012 (0.3)	§11.4.5	§11.4.4 §11.4.6	low	max	10[e]
2d	§8.7	Sensitivity to installation in a water-filled hole[h]	Tension, unconfined, single anchor away from edges[k]	0.012 (0.3)	§11.4.5	§11.4.4 §11.4.6	low	max	10[e]
2e	§8.8	Sensitivity to hole cleaning, installation in submerged concrete[h]	Tension, unconfined, single anchor away from edges[k]	0.012 (0.3)	§11.4.5	§11.4.4 §11.4.6	low	max	10[e]
2f	§8.9	Sensitivity to mixing effort	Tension, unconfined single anchor away from edges[k]	0.012 (0.3)	§11.4.5	§11.4.4 §11.4.6	low	max	10[b]
3	§8.14	Sensitivity to crack width	Tension, unconfined single anchor away from edges[k]	0.020 (0.5)	0.80	§11.4.4 §11.4.6	low	min	10[e]
4	§8.15	Sensitivity to crack width	Tension, unconfined single anchor away from edges[k]	0.020 (0.5)	0.80	§11.4.4 §11.4.6	high	min	10[e]
5	§8.16	Sensitivity to crack width cycling	Sustained tension single anchor away from edges residual capacity, unconfined test[k]	0.004-0.012 (0.1-0.3)	0.90	§11.4.4 §11.4.6 §11.10	low	min	10[e]
6	§8.17	Sensitivity to freeze/thaw conditions[h,m]	Sustained tension residual capacity, confined test[k]	NA	0.90	§11.4.4 §11.4.6 §11.11	high	min	5[b]
7	§8.18	Sensitivity to sustained load[m]	Sustained tension residual capacity, confined test[k]	NA	0.90	§11.4.4 §11.4.6 §11.12	low	min	5[b]

Table 4.4– Test program for evaluating torque-controlled adhesive anchor systems for use in cracked and uncracked concrete: Bond/slip force relationship unconfirmed

Testing				Crack width Δw	Assessment				No. of tests
Test no.	Test ref.	Purpose	Test parameters	inches (mm)	α_{req}	Load & displ.	f_c	h_{ef} [d]	n_{min}
8	§8.19	Sensitivity to installation direction	Tension, unconfined single anchor away from edges[k]	0.012 (0.3)	0.90	§11.4.4 §11.4.6 §11.13	low	max	5[n]
9	§8.20	Torque test	Application of torque, confined, single anchor away from edges[f]	NA	NA	§11.9	high	min	5[e]
Service-condition tests									
10a	§9.4	Tension in low-strength concrete	Tension, unconfined single anchor away from edges[k]	NA	NA	§11.4.4 §11.4.6	low	all	5[e]
10b	§9.4	Tension in high-strength concrete	Tension, unconfined single anchor away from edges[k]	NA	NA	§11.4.4 §11.4.6	high	all	5[e]
10c	§9.4	Tension in low-strength, cracked concrete	Tension, unconfined single anchor away from edges[k]	0.012 (0.3)	NA	§11.4.4 §11.4.6	low	all	5[e]
10d	§9.4	Tension in high-strength, cracked concrete	Tension, unconfined single anchor away from edges[k]	0.012 (0.3)	NA	§11.4.4 §11.4.6	high	all	5[e]
11a	§9.5	Tension at elevated temperatures	Tension, confined single anchor away from edges[k,l,m]	NA	NA	§11.4.4 §11.4.6 §11.14	low	min	5[b]
11b	§9.6	Tension at decreased installation temperature	Tension, confined single anchor away from edges[k,l,m]	NA	NA	§11.15	low	min	5[b]
11c	§9.7	Curing time at standard temperature	Tension, confined single anchor away from edges[k,l,m]	NA	NA	§11.4.6 §11.16	low	min	5[b]
12a	§9.8	Resistance to alkalinity	Slice tests[l,m]	NA	NA	§11.17	low	NA	10[b]
12b	§9.8	Resistance to sulfur[h]	Slice tests[l,m]	NA	NA	§11.17	low	NA	10[b]
13	§9.9	Edge distance in corner condition to develop full capacity	Tension, unconfined single anchor in corner with proximate edges[g,k]	NA	NA	§11.18	low	min max	4[e]
14	§9.10	Minimum spacing and edge distance to preclude splitting on loading	High installation tension (torque or direct) - two anchors near edge[g]	NA	NA	§11.19	low	min	5[e]
15	§9.11	Shear capacity of steel element having a non-uniform cross section[c]	Shear – single anchor away from edges[k]	NA	NA	§11.20	low	min	5[e]

Table 4.4– Test program for evaluating torque-controlled adhesive anchor systems for use in cracked and uncracked concrete: Bond/slip force relationship unconfirmed

Testing				Crack width Δw	Assessment				No. of tests
Test no.	Test ref.	Purpose	Test parameters	inches (mm)	α_{req}	Load & displ.	f_c	h_{ef} [d]	n_{min}
16	§9.12	Seismic tension[h]	Pulsating tension, single anchor away from edges[k]	0.020 (0.5)	NA	§11.4.6 §11.21	low	min max	5[e]
17	§9.13	Seismic shear[h]	Alternating shear, single anchor away from edges[k]	0.020 (0.5)	NA	§11.22	low	min	5[a]
Supplemental tests									
18	§10.2	Minimum member thickness[h]	Installation tests[g]	NA	NA	§11.8	low	max	10[e]

Notes for Table 4.4:

a. Test small, medium and large diameters.

b. Test the ½ in. (M12) diameter or the smallest nominal diameter if it is larger than $^1/_2$ in. (M12).

c. Test is required only for anchors having a cross sectional area, within five anchor diameters of the shear failure plane, that is less than that of a threaded bolt having the same nominal diameter as the anchor.

d. Where the manufacturer's printed installation instructions specify multiple embedment depths for a single anchor diameter, test the anchor at the minimum or maximum embedment depth as noted, whereby $h_{ef,max}/h_{ef,min} \leq 5.0$. See also Section 5.7.2.

e. Test all diameters.

f. This test confirms the value of T_{inst} to be used for the test program. As such, it should be conducted before performing other tests requiring application of torque.

g. Minimum member thickness h_{min} shall be used for these tests.

h. Optional test.

i. (not used)

j. Install anchors with 50% of the recommended installation torque T_{inst}.

k. See Section 5.6.2.1.1 for torque requirements.

l. These tests shall be permitted to be performed with threaded steel rod substituted for the anchor element. In this case, reference tests must be performed with threaded steel rod as well.

m. If these tests have been previously been performed in accordance with Table 4.1 or Table 4.2 using the same adhesive as that employed for the torque-controlled adhesive anchor and the correct static load, they may be omitted here.

n. For overhead and horizontal orientations, test the largest diameter for which recognition is sought.

4.5 Assessment for multiple anchor element types – adhesive anchors:

4.5.1 In cases where the assessment encompasses multiple anchor element material types, the entire assessment shall be permitted to be performed with one anchor element type; however, the other anchor element types shall be subjected to additional tests in accordance with Table 4.5.

Table 4.5 – Additional tests required for assessment of multiple anchor element types for adhesive anchors in accordance with Section 4.5

Nature of variation from tested anchor element[1]			Reference	Test No.	Purpose	Requirement
Material	Geometry	Surface coating				
-	X	X	Table 4.1	6	Torque test[2]	See Section 11.9.
-	X	X	Table 4.2	9		
-	X	X	Table 4.1	10	Corner test	See Section 11.18.
-	X	X	Table 4.2	14		
-	X	X	Table 4.1	11	Min. spacing and edge dist.	See Section 11.19.
-	X	X	Table 4.2	15		
X	X	-	Table 4.1	12	Shear test to determine shear capacity as governed by steel failure.	Required for anchor elements with reduced cross section, see Section 9.11.
X	X	-	Table 4.2	16		
X	X	-	Table 4.2	18	Seismic shear test	Optional test, see Section 11.22.

[1] In cases where the anchor element varies in more than one characteristic (material, geometry, surface coating), test requirements indicated for each variation shall apply.
[2] In cases where the results of torque testing can be shown to be statistically equivalent to the tested anchor element type, repetition of corner and minimum spacing and edge distance tests shall be permitted to be omitted.

4.6 Assessment for multiple anchor element material types – torque controlled adhesive anchors:

4.6.1 In cases where the assessment encompasses multiple anchor element material types whereby the anchor elements are identical with respect to geometry and surface finish but are fabricated from metals that differ in chemical content, mechanical properties or production method, the entire assessment shall be permitted to be performed with one anchor element type; however, the other anchor element types shall be subjected to torque tests and shear tests in accordance with Table 4.6.

4.6.2 In cases where the assessment encompasses multiple anchor element material types whereby the anchor elements are not identical with respect to either geometry or surface finish, perform separate reference and reliability tests in accordance with Table 4.3 or Table 4.4 for each anchor element geometry and surface finish. If the results of the reference and reliability tests for the anchors of each anchor element material and production method are statistically equivalent, the service-condition tests shall be permitted to be performed for one anchor material and production method only. Otherwise, perform the complete test program for each anchor material and production method.

Table 4.6 – Additional tests required for assessment of multiple anchor element material types for torque-controlled adhesive anchors in accordance with Section 4.6

Reference	Test No.	Purpose	Requirement
Table 4.3	9	Torque test to establish statistical equivalence with tested anchor element type.	Statistical equivalence (def. § 2.1.26) required for each anchor element material type. If statistical equivalence cannot be shown, all tests must be repeated for that anchor element.
Table 4.4	9		
Table 4.3	16	Shear test to determine shear capacity as governed by steel failure.	Required for anchor elements with reduced cross section, see Section 9.11.
Table 4.4	15		
Table 4.3	18	Seismic shear test	Optional test, see Section 11.22.
Table 4.4	17		

4.7 Assessment for alternate drilling methods:

4.7.1 The qualification of the anchor for use with drilling methods other than carbide bit rotary-hammer drilling shall be predicated on fulfilment of the requirements of this section.

4.7.1.1 Perform supplemental tests in accordance with Table 4.7 using the alternate drilling method. Install anchors in accordance with the manufacturer's published installation instructions.

4.7.1.2 The results of supplemental tests as required in Section 4.7.1.1 shall be shown to be statistically equivalent (def. § 2.1.26) to the results of corresponding tests conducted with carbide rotary-hammer bits in accordance with this criteria. If this requirement is not met, recognition of the alternate drilling method is dependent on the successful completion of all tests as described in this criteria.

4.7.1.2.1 Exception: Testing for the shear capacity of the anchor element need not be repeated, see Table 4.1, Test No. 12, Table 4.2, Test No. 16, Table 4.3, Test No. 16 and Table 4.4, Test No. 15.

4.7.1.2.2 Exception: Testing using rotary-hammer drilling shall also be valid for percussive drilling (e.g., pneumatic rock drills) without supplementary tests. Testing using percussive drilling shall not be valid for rotary-hammer drilling without supplemental tests as described in this section.

Table 4.7 – Required supplemental tests for each alternate drilling method

Reference	Test Nos.														
	Reference				Installation safety							Crack width		Slip/bond force	
Table 4.1	1a	1b			2a	2b*	2c*	2d*	2f*	2g*	2h*				
Table 4.2	1a	1b	1c	1d	2a	2b*	2c*	2d*	2f*	2g*	2h*	3	4		
Table 4.3	1a	1b			2b	2c*	2d*	2e*				3	4	10a	10b
Table 4.4	1a	1b			2b	2c*	2d*	2e*				3	4		

*Optional tests, required only if conditions of use associated with these tests are sought for recognition

5.0 REQUIREMENTS FOR TEST SPECIMENS, ANCHOR INSTALLATION, AND TESTING

5.1 Test samples:

5.1.1 Sampling of the anchors for tests under this criteria shall comply with Sections 3.1, 3.3 and 3.4 of AC85 and this section.

5.1.2 The independent testing and evaluation agency (see Section 13.0) shall visit the manufacturing or distribution facility, shall randomly select anchors for testing, and shall verify that the samples are representative of the production of the manufacturer as supplied to the marketplace.

5.1.3 To test newly developed anchors that are not in production, use samples produced by the expected production methods. After production has begun, perform identification and reference tests to verify that the constituent materials have not changed, and that the performance of the production anchors is statistically equivalent (def. § 2.1.26) to that of the anchors originally evaluated.

5.1.4 When internally threaded anchors are supplied without fastening items such as bolts, the manufacturer shall specify the bolts to be used.

5.1.5 The sample sizes given in Table 4.1, Table 4.2, Table 4.3, and Table 4.4 are the minimum required to satisfy this criteria. At the discretion of the independent testing and evaluation agency or manufacturer, the sample size shall be permitted to be increased.

5.1.6 Where tension tests on anchor elements are required to establish steel properties, a minimum of three replicates shall be performed.

5.2 Concrete for test members:

5.2.1 Concrete used in testing shall meet the requirements of this section. To assess the performance of an anchor for use in a concrete outside of the scope of this criteria, additional tests shall be conducted with that concrete.

5.2.2 Concrete mix designs shall follow recommendations for proportioning in the Portland Cement Association's *Design and Control of Concrete Mixtures*, Thirteenth Edition; ACI 211.1; IBC Chapter 19 (ACI 318) or UBC Chapter 19. Proportions may be varied to meet local requirements and to achieve desired nominal compressive strength during the testing period. The reason for any variation shall be explained in the test report.

5.2.3 Coarse and fine aggregates in concrete shall comply with ASTM C 33. The aggregate description shall include the rock and mineral components, shape, hardness, and the maximum size and grading specification. The maximum aggregate size shall be 3/4 in. or 1 in. (19 mm or 24 mm).

5.2.4 For general qualification for use of the anchor system in normal- and lightweight concrete, use portland cement conforming to ASTM C 150. The concrete mixture shall not include materials such as slag, fly ash, silica fume or limestone powder. If a nonstandard concrete mixture is used for test members, report the concrete mixture components and proportions. In this case, qualification will be specific to the tested concrete mixture.

5.2.5 Test anchors in test members cast of concrete within two nominal compressive strength ranges:

Low-strength concrete: 2,500 to 4,000 psi (17 to 28 MPa); and

High-strength concrete: 6,500 to 8,500 psi (46 to 60 MPa).

5.2.5.1 It shall be permitted to test anchors in test members cast of concrete with a nominal compressive strength of 2,000 psi (14 MPa); however, the results shall not be normalized to a higher compressive strength.

5.2.6 Test members shall conform to the requirements of Section 5.3.

5.2.7 Test members shall be at least 21 days old at the time of anchor testing.

5.2.8 See Section 10.1 for additional requirements in conjunction with round-robin testing for adhesive anchors.

5.3 Requirements for test members:

5.3.1 Test members shall conform to the requirements of ASTM E 488. Where the requirements of ASTM E 488 conflict with this criteria, the provisions of this criteria shall take precedence.

5.3.2 Concrete batch requirement: Reliability tests and the reference tests to which they are compared shall be conducted in concrete originating from the same batch.

5.3.2.1 A batch is defined as one mixer-truck delivery from a batch plant (see Fig. 5.1).

5.3.2.2 A batch plant is defined as a facility which receives and stores concrete ingredients, selects and combines proportions, and dispenses the mixture into a mixer-truck.

Fig. 5.1 – Concept of concrete batches

5.3.3 Casting, curing and strength determination of test members:

5.3.3.1 Cast test member either horizontally or vertically. If the test member is cast vertically, the maximum height of a concrete lift shall be 5 feet (1.5 m).

5.3.3.2 Sample, mold and field cure compressive strength cylinders in accordance with ASTM C 31. Expose cylinders to the same environmental conditions as the test member. Remove molds from the cylinders concurrent with removal of forms and curing membranes from the test member.

5.3.3.3 Test member concrete compressive strength at the time of anchor testing shall be determined from compression tests conducted on concrete cylinders in accordance with ASTM C 39 or cores extracted from the test member in accordance with ASTM C 42. It shall be permitted to linearly interpolate mean strength values determined at the beginning and end of a test series or to develop a strength-age relationship for the concrete test member on the basis of compression tests conducted at uniform intervals throughout the duration of the test program.

5.3.4 Test members for tests in uncracked concrete: Test members shall be unreinforced except as required to permit efficient handling of the test member or distribution of reaction loads from test equipment. Position such reinforcing so that the capacity of the tested anchor is not affected. This requirement shall be considered to be met for anchors tested in tension if the reinforcing is located outside of a virtual cone projecting from the embedded end of the anchor to the concrete surface with an internal vertex angle of 120 degrees.

5.3.5 Test members for tests in cracked concrete: Test members shall be designed to produce approximately planar cracks of uniform width throughout the thickness of the component. The cracks should be spaced sufficiently to facilitate testing of individual anchors placed in a crack without influence from neighboring cracks. For test members that use internal reinforcement to control the crack width, the reinforcement shall be placed so, that there is no influence on the performance of the anchors. See Fig. 5.5 for an example test slab configuration. (For additional guidance on testing in cracked concrete, see R. Eligehausen, L. Mattis, R. Wollmershauser, M. Hoehler, "Testing Anchors in Cracked Concrete", *Concrete International*, Vol. 26, No. 7, July 2004, pp. 66-71.)

5.3.5.1 The crack width shall be controlled by reinforcing bars oriented perpendicular to the crack plane and distributed symmetrically over the test member cross section. The ratio of tension reinforcement (top and bottom layers) to the area of the crack plane shall be approximately 1%.

5.3.5.2 The reinforcement shall be permitted to cross the potential concrete cone breakout surface associated with the test anchor. The centerline-to-centerline distance between any reinforcement and the anchor shall not be less than $0.4h_{ef}$. Greater values for spacing of reinforcement are allowed e.g. in the case of narrow concrete components (e.g. width x depth = 20 in. (500 mm) x 10 in. (250mm)), where it is ensured that planar cracks of uniform width throughout the thickness of the component are produced and the crack width requirements of this criteria are fulfilled. Furthermore smaller values for center-to-center distance between reinforcement and anchor are allowed in case of deep embedments where it is ensured that the anchorage mechanism is not influenced by the reinforcement. It shall be permitted to debond reinforcing over a length of 3 in. (75 mm) on either side of the anticipated crack plane location using tape, plastic tubing or a debonding agent.

5.3.5.3 Crack formation and crack opening: An acceptable method is described in Section 5.3.5.4. Other methods shall be permitted subject to the requirements of this criteria.

5.3.5.4 Initiate and control the crack progression with planar sheet metal shapes (crack inducers) placed in the formwork prior to casting of the test member. Position crack inducers such that the capacity of the tested anchor is not affected by their presence. Extend tension reinforcing as required in Section 5.3.5 beyond the ends of the test member to facilitate application of external tension loads directly to the reinforcing. Apply external loading to both ends of the reinforcing to facilitate development of uniform strain over the length of the reinforcing. See Fig. 5.6 for an example test setup.

5.3.5.5 The average of the crack widths for each test series, measured by the two crack measurement devices for each anchor before the load application shall be equal to or greater than the specified crack width for that test series. Individual crack widths shall be within ±15% of the specified crack width for the test series.

5.4 Anchor installation:

5.4.1 General requirements:

5.4.1.1 Anchor installation shall be according to the manufacturer's printed installation instructions, except as otherwise required in this test criteria. Report any deviations.

5.4.1.2 Install anchors in a formed face of the concrete, or in concrete with a steel-troweled finish.

5.4.1.3 Drilled holes for anchors shall be perpendicular (+/- 6 degrees) to the surface of the concrete test member.

5.4.1.4 The components of the anchor on which the reliability and capacity depend shall not be exchanged. Bolts, nuts, and washers not supplied with the anchors shall conform to the specifications given by the manufacturer, and these specifications shall be included in the test report.

5.4.2 For installation of anchors in cracks, use the following procedure:

1. With the test member unloaded, drill the hole for the anchor in a hairline crack that is sufficiently planar to ensure that the crack will approximately bisect the anchor location over the extent of the anchor load transfer zone.
2. Visually verify the positioning of the anchor in the crack, e.g., by means of a boroscope or similar device.

5.5 Drill bit requirements:

5.5.1 Holes drilled with a hammer (rotary-percussive) drill shall be made using carbide-tipped, rotary-hammer bits meeting the requirements of ANSI B212.15.

5.5.2 For drill bits not covered by ANSI B212.15 (e.g., core bits), the independent testing and evaluation agency shall measure and report the the cutting diameter of the bits.

5.6 Torque requirements:

5.6.1 Adhesive anchors:

5.6.1.1 Unless otherwise specified in this criteria, adhesive anchors shall not be torqued prior to testing.

5.6.2 Torque-controlled adhesive anchors:

5.6.2.1 Where specified in this criteria, torque-controlled adhesive anchors shall be torqued in accordance with Section 5.6.2.1.1.

5.6.2.1.1 Apply the installation torque T_{inst} specified in the manufacturer's printed installation instructions using a calibrated torque wrench having a measuring error within ±5% of the specified torque. A minimum of ten minutes after the initial application of T_{inst}, loosen the nut or anchor bolt and re-apply torque to a level of $0.5T_{inst}$.

5.7 Test methods:

5.7.1 Test anchors in conformance with ASTM E 488 and this criteria. Where differences occur, this criteria shall take precedence over ASTM E 488.

5.7.2 In all tension tests, steel failure shall be avoided.

5.7.2.1 In order to avoid steel failure, unconfined and confined tension tests may be performed with an anchor element having a documented strength exceeding the product specification, subject to the following:

1. The geometry and coatings of the substitute anchor element shall be identical to the product specification, or
2. It shall be demonstrated that the substitute anchor element does not affect the function or performance of the anchor.

5.7.2.1.1 Exception: In testing of adhesive anchors in accordance with Tables 4.1 and 4.2 where use of a high-strength steel anchor element (minimum strength equivalent to A 193 Grade B7) is insufficient to prevent steel failure, the anchor embedment may be reduced. In these cases, the effectiveness of installation methods, including hole cleaning and adhesive injection for all orientations for which recognition is sought, shall be checked by other means as described in Section 5.7.2.1.2.

5.7.2.1.2 For cases where the embedment depth must be reduced in order to avoid failure modes other than bond failure, the following test method is suggested to verify the installation method:

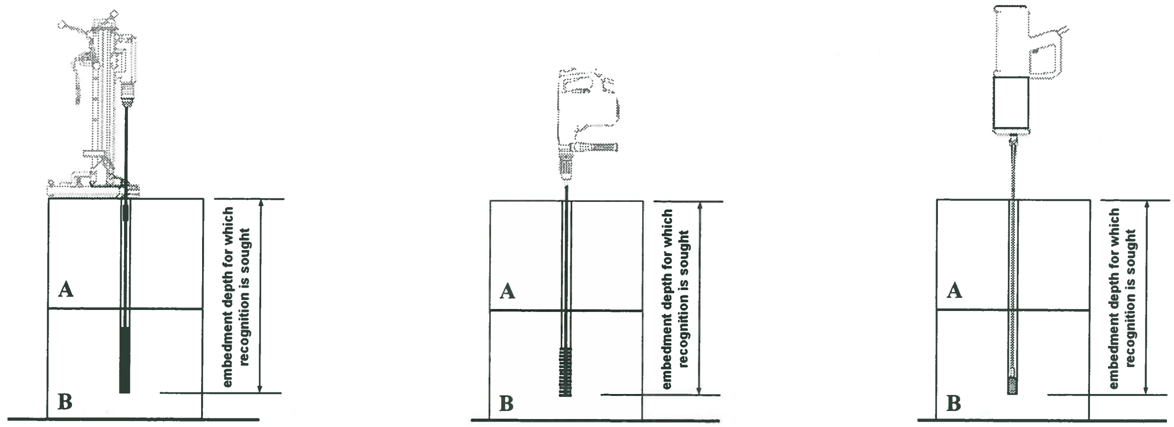
Step 1: Stack concrete blocks as shown in Figure 5.2a as required to achieve the desired embedment and perform the drilling operation (core drill shown, other drilling methods may be used as appropriate). Seal the interface between the blocks.

Step 2: Clean the hole in accordance with the procedures described in the manufacturer's published installation instructions. See Figure 5.2b.

Step 3: Perform adhesive injection in accordance with the procedures described in the manufacturer's published installation instructions. Limit injection depth to the bottom block. See Figure 5.2c.

Step 4: Remove the upper block and install the anchor element in accordance with the procedures described in the manufacturer's published installation instructions. See Figure 5.2d.

Step 5: Perform a confined tension test to failure. See Figure 5.2e.

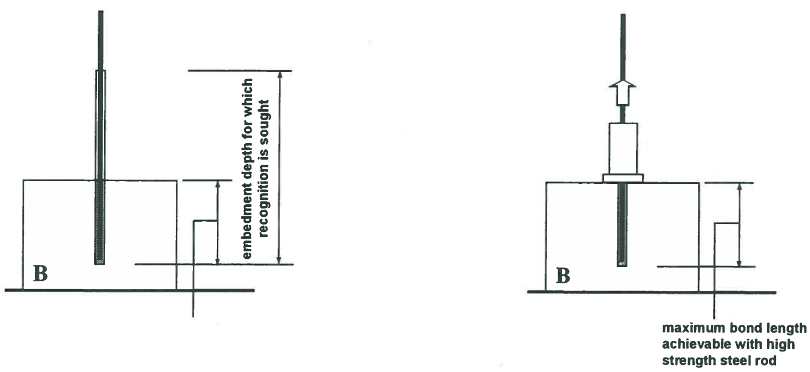


Step 1: Drill — (a)

Step 2: Clean — (b)

Step 3: Inject — (c)

FIGURE 5.2—SUGGESTED METHOD FOR ESTABLISHING THE BOND STRENGTH AT DEEPER EMBEDMENTS



Step 4: Install bar — (d)

Step 5: Pull to failure — (e)

FIGURE 5.2—SUGGESTED METHOD FOR ESTABLISHING THE BOND STRENGTH AT DEEPER EMBEDMENTS (Continued)

5.7.2.2 For test series 3 and 4 in Table 4.1 and test series 6 and 7 in Table 4.2, in order to build the proper level of bond stress into the assessment, it shall be demonstrated that Eq. 5.1 is fulfilled for the h_{min} value used. If Eq. 5.1 is not fulfilled with the results of the unconfined tests, the embedment depth shall be increased until Eq. 5.1 is fulfilled, whereby steel failure is avoided in all tests. Alternatively, confined tests shall be conducted with a suggested embedment of $7d$ in accordance with Section 5.7.3.2 and the values of $\overline{N}_{oi}$ calculated in accordance with Eq. 5.2 shall be substituted in Eq. 8.2 and Eq. 8.3.

$$k_m \leq 24 \text{ (in., lb.)} \qquad \text{Eq. 5.1}$$

$$k_m \leq 10 \text{ (N, mm)}$$

where:

$k_m = \dfrac{\overline{N}_{oi}}{h_{ef}^{1.5}\sqrt{f_{c,test,i}}}$ (in., lb) [N, mm]

$\overline{N}_{oi}$ = mean ultimate tension load measured in unconfined tests

$f_{c,test,I}$ = concrete compressive strength in test series i

$$\overline{N}_{oi} = \alpha_{setup} \cdot \overline{N}_{oi,conf} \qquad \text{Eq. 5.2}$$

$\overline{N}_{oi,conf}$ = mean ultimate tension load measured in confined reference tests at $h_{ef} \approx 7d$

5.7.3 The minimum embedment depth at which reliability and reference tests are conducted shall be that at which bond failure occurs in order to provide the proper level of bond stress for the assessment. Unconfined and confined tension tests:

5.7.3.1 Unconfined tension tests shall be conducted where specified. Fig. 5.3 shows the unconfined tension test setup, whereby the supports are spaced a suitable distance from the anchor to permit the unrestricted development of a conical concrete fracture surface.

5.7.3.2 Confined tests are specified primarily to reduce the size and quantity of concrete test members required. Fig 5.4 shows the confined tension test setup for adhesive anchors, whereby the reaction force is transferred into the concrete in close proximity to the anchor element. The hole in the confining plate shall be 1.5 d_o to 2.0 d_o. The hole shall be centered in the confining plate. The thickness shall be greater than or equal to d. The distance from the hole to the edge of the confining plate shall not be less than 2 inches (51 mm). The confining plate shall possess a smooth surface. A sheet of tetrafluoroethylene (TFE), polytetrafluoroethylene (PTFE), fluorinated ethylene propylene (FEP), or perfluoroalkoxy (PFA) of 0.5 ± 0.1 mm (0.020 ± 0.004 in.) corresponding to the area of the confining plate shall be placed between the confining plate and the concrete surface.

5.7.4 Tests in cracked concrete:

5.7.4.1 Perform tests in concrete test members meeting the requirements of Section 5.2. Initiate cracking in the test member and install the anchor in accordance with Section 5.4 so that the axis of the anchor is coincident with the crack plane. Install instrumentation for monitoring crack-opening width. Monitor crack-opening width using dial gages or electronic transducers located roughly symmetrically on either side of the anchor on an axis oriented perpendicular to the crack plane to permit interpolation for the crack width at the anchor location. The distance from any crack-width measurement point to the anchor centerline shall be kept as small as possible but shall not exceed the greater of $1.0h_{ef}$ or 5 inches (125 mm). Increase the crack width by the specified crack value prior to applying external loads to the anchor. Verify by suitable means that the system used for crack formation and the associated test procedures produce cracks that remain parallel during the performance of tests. The crack width as measured at the opposite face of the test member in line with the anchor location (or as estimated based on the crack width measurement on each side of the test member as close to the opposite face as possible) should be approximately equal to the crack width as measured on the anchor side.

5.7.4.2 Subject the anchor to the specified loading sequence while monitoring the crack opening width at the surface.

5.7.4.3 Continuously record the applied load, corresponding anchor displacement and crack width during the test. Use a sampling frequency appropriate for the load or strain rate employed for the test.

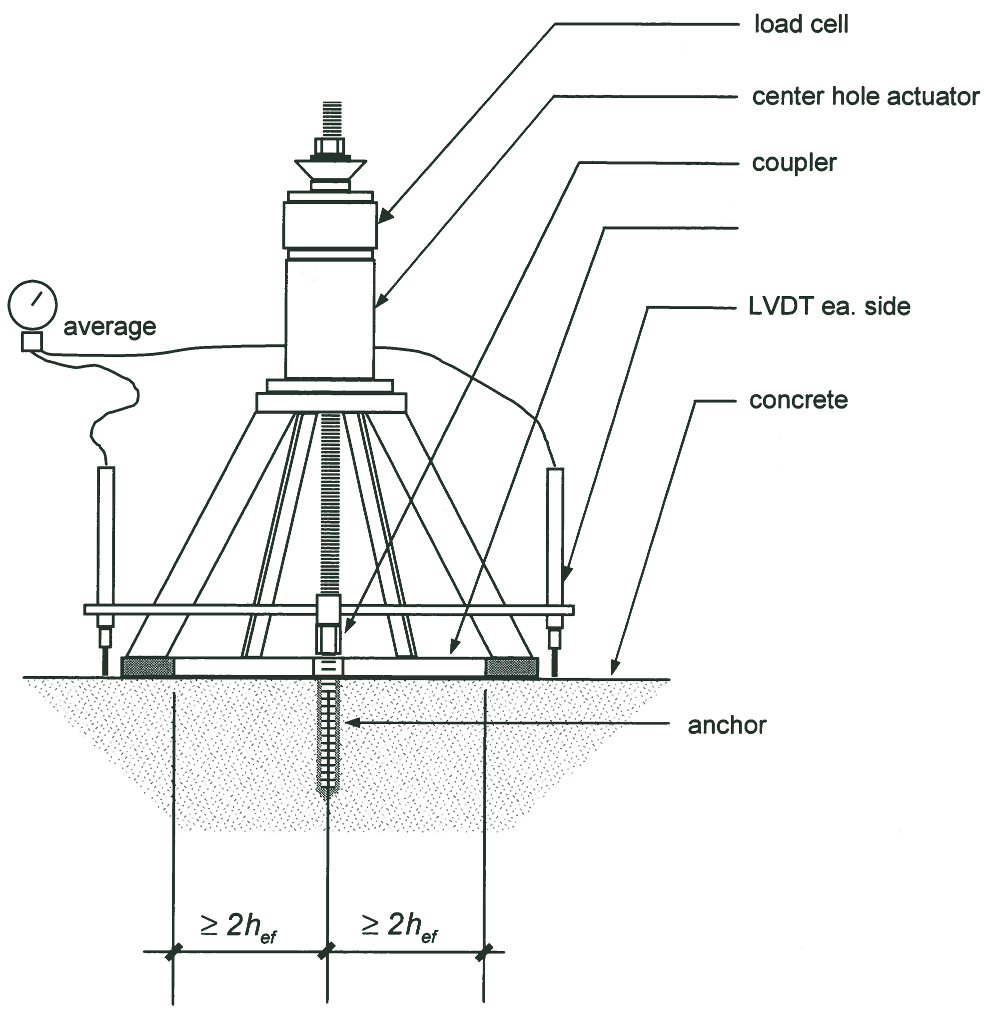


Fig. 5.3 – Example of an unconfined tension test setup for adhesive anchors

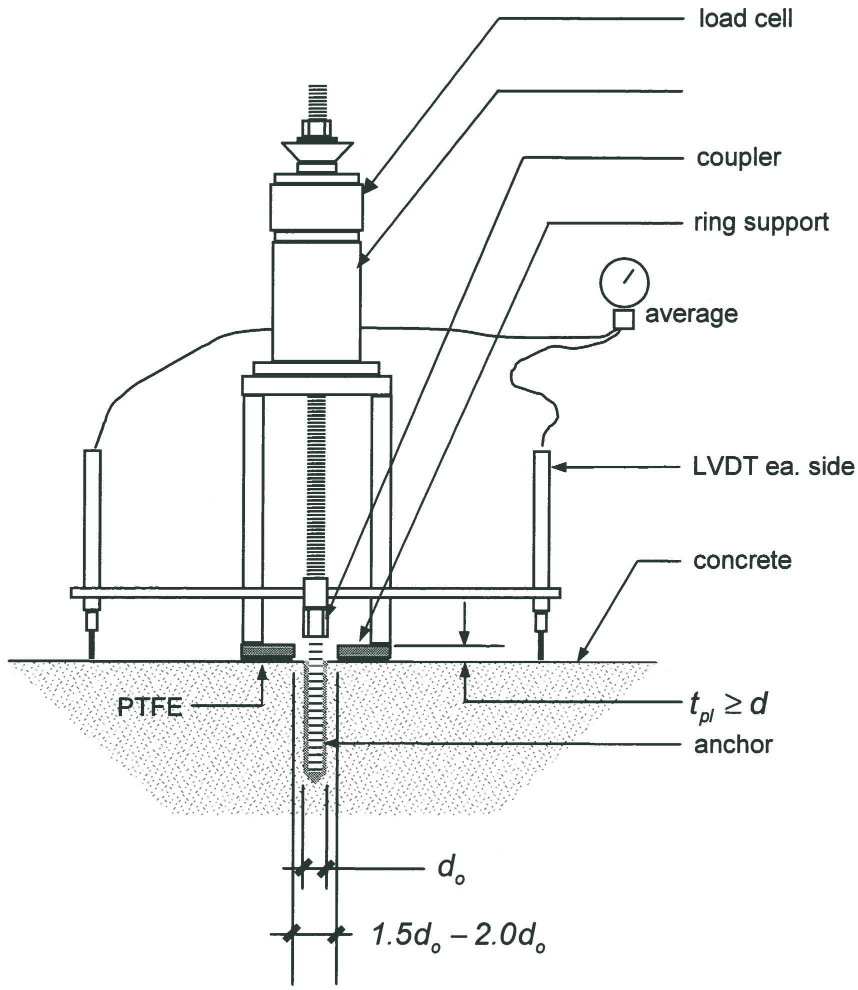


Fig. 5.4 – Example of a confined tension test setup for adhesive anchors

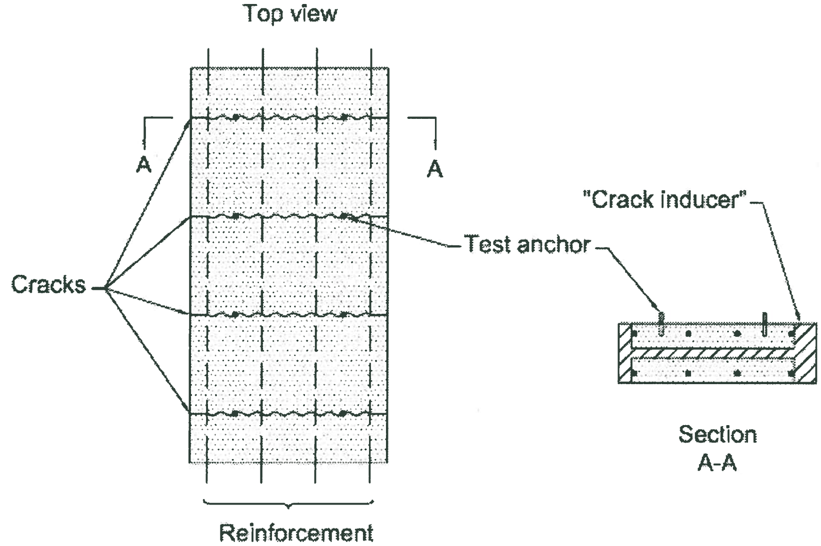


Fig. 5.5 – Example of test slab for testing in cracked concrete

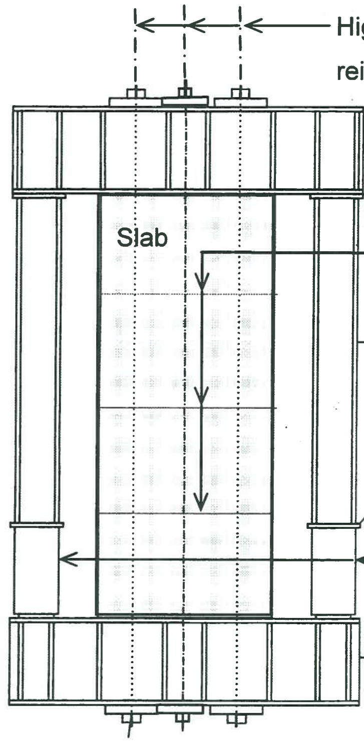


Fig. 5.6 – Example of test rig for testing in cracked concrete

6.0 REQUIREMENTS FOR ANCHOR IDENTIFICATION

6.1 Basic Requirements:

6.1.1 The following information shall be provided in the evaluation report:

6.1.1.1 Product description, including:

a. Generic or trade name;

b. Anchor element dimensions, constituent materials and appropriate physical properties, including tensile strength, hardness and coatings; and

c. A description of the adhesive components including the adhesive name, packaging system, mixing ratios, gel time, cure time, storage information and shelf life.

6.2 Verification:

6.2.1 The testing and evaluation agency shall check the characteristics reported in accordance with Section 6.1.1.1 against the manufacturer's product specifications.

6.3 Fingerprinting of adhesive materials:

6.3.1 The adhesive components used for the qualification testing shall be tested to establish a standard fingerprint for comparison with future production as part of the required quality control inspections. It shall be permitted to test the components separately or their mixture, as appropriate. The manufacturer shall select from the following list a minimum of three (3) fingerprint tests for this purpose:

a. infrared absorption spectroscopy according to ASTM E 1252;
b. bond strength according to ASTM C 882 or equivalent method;
c. specific gravity according to ASTM D 1875;
d. gel time according to ASTM D 2471;
e. viscosity according to ASTM D 2556, F 1080 or equivalent method;
f. other tests that may be appropriate for the specific product and that can be shown to provide positive identification.

6.3.2 Detailed test protocols for the selected test methods shall be provided in the test report and shall include acceptable tolerance ranges, applicable options and any variations from the cited test standard. They shall be acceptable to both the independent testing and assessment agency and ICC ES staff.

6.4 Packaging:

6.4.1 Packaging of the adhesive materials shall include the following:

a. Manufacturer's name and address.
b. Lot number.
c. Packing date and shelf life or product expiration date.
d. ICC-ES ESR number (ESR-XXXX).
e. Name of the inspection agency used for manufacturing quality assurance (see Section 14.2).
f. Manufacturer's printed installation instructions and application information.

7.0 REFERENCE TESTS

7.1 Purpose:

7.1.1 Reference tests are performed in each batch of concrete to obtain baseline values for reliability and service-condition tests where reference values are required to assess the effects of sub-optimal hole cleaning, temperature variation, etc. on anchor performance.

7.1.2 In general, reference tests shall be performed as confined tension tests (see Section 5.7.3). The use of confined tests is based on the following considerations:

1. Confined tests do not generate large spall cones, and as such serve to reduce the volume of concrete required for the test program.
2. Confined tests measure the bond strength of the anchorage as opposed to the concrete capacity associated with concrete failure modes such as concrete cone breakout. As such, they are suitable to assess the effects of temperature variation, sub-optimal hole cleaning, etc. on anchor performance.

7.2 Required tests:

7.2.1 Required reference tests are given in Table 4.1 for anchors to be qualified for use in uncracked concrete only and in Table 4.2 for anchors to be qualified for use in both uncracked and cracked concrete. Reference test requirements for torque-controlled adhesive anchors are given in Table 4.3 or Table 4.4.

7.2.2 Reference tests shall be conducted in the same concrete batch used for the reliability or service-condition tests to which they are compared. Reference tests may be used for comparison with more than one series of reliability or service-condition tests. See Fig. 7.1 for an example test layout.

7.2.3 The anchor diameters for which reference tests are required shall correspond to the requirements for the reliability or service-condition tests for which the reference tests are performed.

7.2.3.1 It shall be permitted to perform reference tests for torque-controlled adhesive anchor systems with the anchor element replaced by Unified National Coarse (UNC) threaded rod of equivalent nominal diameter if the corresponding reliability or service condition tests are performed with threaded rod as well.

7.2.4 Reference tests for the assessment of tests conducted in uncracked concrete shall be performed in uncracked concrete. Reference tests for the assessment of tests conducted in cracked concrete shall be performed in cracked concrete.

7.3 Conduct of tests:

7.3.1 Prepare test members, install anchors and test in accordance with Section 5.0.

7.3.2 Perform tests in dry concrete.

7.3.3 Perform tests with concrete and anchor at standard temperature.

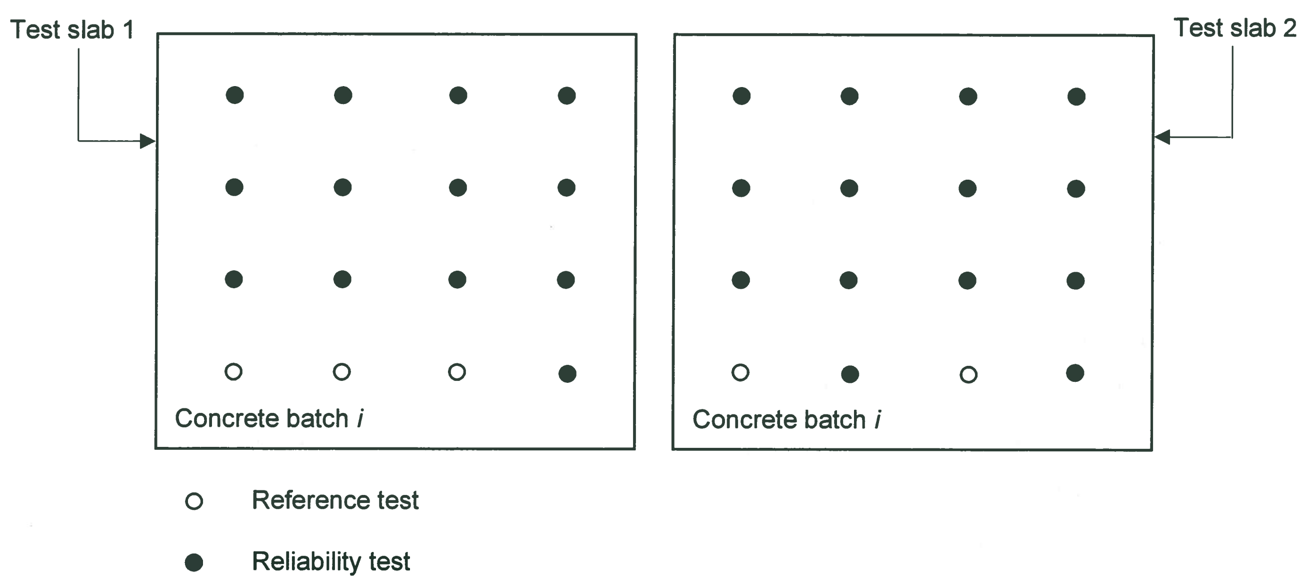


Fig. 7.1 – Example test layout

8.0 RELIABILITY TESTS

8.1 Purpose:

8.1.1 Reliability tests are performed to establish that the anchor is capable of safe, effective behavior under normal and adverse conditions, both during installation and in service.

8.2 Required tests:

8.2.1 Required reliability tests are given in Table 4.1 for adhesive anchors to be qualified for use in uncracked concrete only and in Table 4.2 for adhesive anchors to be qualified for use in both uncracked and cracked concrete. The requirements for torque-controlled adhesive anchors are given in Table 4.3 and Table 4.4.

8.2.2 Drill hole tolerance: No tests for the influence of drill tolerance on anchor behavior are required.

8.3 Conduct of tests:

8.3.1 Prepare test members, install anchors and test in accordance with Section 5.0 unless otherwise noted.

8.3.2 Perform tests in dry concrete unless otherwise noted.

8.3.3 Perform tests with air, concrete and anchor at standard temperature unless otherwise noted.

8.4 Installation safety tests:

8.4.1 Installation safety tests are intended to assess the sensitivity of the tested system to variations in installation parameters as are likely to be experienced in practice. They are not intended to address gross installation errors. Gross installation errors are characterized by significant deviations from the manufacturer's printed installation instructions or design specifications. These include but are not limited to:

a. deviations from the specified embedment depth;
b. use of a nominal diameter drill bit other than that specified;
c. incorrect assembly or operation of the adhesive mixing and dispensing equipment;
d. use of the product in base materials other than structural concrete;
e. use of the product in concrete exhibiting compressive strength outside of the specified range;
f. use of the product in base materials having a temperature outside of the specified range for the product;
g. violation of specified gel and cure times; and
h. violation of storage and shelf life restrictions for the adhesive.

8.5 Sensitivity to hole cleaning, dry substrate (Table 4.1, Test No. 2a; Table 4.2, Test No.2a; Table 4.3, Test No. 2b; and Table 4.4, Test No. 2b):

8.5.1 Purpose: These installation safety tests are used to assess the sensitivity of the anchor tension capacity to the degree of hole cleaning employed prior to anchor installation.

8.5.2 General test conditions: Perform confined tension tests in uncracked concrete.

8.5.2.1 Exception: Tests on torque-controlled adhesive anchors shall be unconfined tension tests in cracked concrete.

8.5.3 The test description provided here presumes a method of hole cleaning that includes blowing out the hole with air and cleaning the hole wall with a brush. Other cleaning methods are permitted; however, the manufacturer's published installation instructions for the product shall be reasonable with respect to the extent and complexity of the cleaning process and shall contain sufficient specificity to permit the determination of a numeric (50%) reduction of hole cleaning effort. For hole cleaning methods involving blowing and brushing operations, such specificity shall include as a minimum the following:

a. requirements for all equipment to be used in the hole cleaning process, including air/vacuum pressure, nozzle construction and brush dimension and materials as applicable;
b. acceptable methods and minimum number and duration of operations required for removal of drilling debris from hole;
c. acceptable methods and minimum number and duration of operations required for removal of dust or drilling flour from the hole wall; and
d. the required sequence of operations.

8.5.4 Drill the hole downwards to the depth defined by the manufacturer. Clean the hole with 50% of the specified minimum number of operations in the specified sequence, rounding down to the next whole number of operations. For example, if a total of four blowing and four brushing operations are specified install the anchor with only two blowing and two brushing operations.

8.5.4.1 If the manufacturer's published installation instructions do not contain sufficient specificity with respect to hole cleaning as defined in Section 8.5.3 to permit the determination of a numeric reduction of hole cleaning effort per this section, or if the required equipment is not specified as defined in Section 8.5.3a., the tests shall be conducted without hole cleaning.

8.5.4.2 Qualification for water-flushed holes: If manufacturer's printed installation instructions require flushing of the hole with water prior to anchor installation, this test is not required.

8.6 Sensitivity to hole cleaning with installation in water-saturated concrete (Table 4.1, Test No. 2b; Table 4.2, Test No. 2b; Table 4.3, Test No. 2c; Table 4.4, Test No. 2c):

8.6.1 Purpose: These optional installation safety tests are used to assess the sensitivity of the adhesive material to hole cleaning for applications in water-saturated concrete.

8.6.2 General test conditions: Perform confined tension tests in uncracked concrete.

8.6.2.1 Exception: Tests on torque-controlled adhesive anchors shall be unconfined tension tests in cracked concrete.

8.6.3 Qualification for use with carbide drill bits: Drill a pilot hole downwards to the specified hole depth but with a bit approximately half the diameter of the specified hole diameter. Fill the pilot hole with tap water and ensure that the hole remains flooded for a minimum of eight days (192 hours) or until it can be shown that the concrete is saturated over a diameter of 1-1/2 times the anchor hole diameter as measured from the center of hole. Immediately prior to installing the anchor, remove all freestanding water with a vacuum and re-drill the existing hole with the specified drill bit diameter. Clean the hole in accordance with the reduced cleaning effort specified in Section 8.5.3. Load the anchor to failure with continuous measurement of load and displacement. Other methods of achieving saturation of the concrete (such as immersion of the test member) shall be permitted. If methods other than those described above are used it shall be shown by appropriate methods that the concrete in the area of the anchorage is water saturated.

8.6.4 Qualification for water-flushed holes: Prepare the hole in accordance with Section 8.6.3; however, re-drill the pilot hole down-hand with the specified drill bit. If manufacturer's printed installation instructions specify flushing of the hole with water prior to anchor installation, it shall be permitted to flush the hole with tap water prior to installing the anchors. Immediately prior to installing the anchors, remove freestanding water from the hole with a vacuum. Load the anchor to failure with continuous measurement of load and displacement.

8.7 Sensitivity to hole cleaning with installation in a water-filled hole in saturated concrete (Table 4.1, Test No. 2c; Table 4.2, Test No. 2c; Table 4.3, Test No. 2d; Table 4.4, Test No. 2d):

8.7.1 Purpose: These optional installation safety tests are used to assess the sensitivity of the adhesive material to hole cleaning for applications in water-saturated concrete where the drilled holes contain standing water at the time of anchor installation.

8.7.2 General test conditions: Perform confined tension tests in uncracked concrete.

8.7.2.1 Exception: Tests on torque-controlled adhesive anchors shall be unconfined tension tests in cracked concrete.

8.7.3 Qualification for use with carbide drill bits: Prepare and clean the hole in accordance with Section 8.6.3; however, re-fill the hole with tap water immediately prior to installing the anchor and install the anchor in the water-filled hole. Load the anchor to failure with continuous measurement of load and displacement.

8.7.4 Qualification for water-flushed holes: Prepare and clean the hole in accordance with Section 8.6.4; however, re-fill the hole with tap water immediately prior to installing the anchor and install the anchor in the water-filled hole. Load the anchor to failure with continuous measurement of load and displacement.

8.8 Sensitivity to hole cleaning with installation in submerged concrete (Table 4.1, Test No. 2d; Table 4.2, Test No. 2d; Table 4.3, Test No. 2e; Table 4.4, Test No. 2e):

8.8.1 Purpose: These optional installation safety tests are used to assess the sensitivity of the adhesive material to hole cleaning for applications in submerged concrete.

8.8.2 General test conditions: Perform confined tension tests in uncracked concrete.

8.8.2.1 Exception: Tests on torque-controlled adhesive anchors shall be unconfined tension tests in cracked concrete.

8.8.3 The surface of the water-saturated concrete test member shall be covered with tap water to a minimum depth of ½-inch (12 mm) for the duration of the test, including anchor installation and tension testing. Drill the hole downward in the submerged concrete and clean the hole in accordance with the reduced cleaning effort specified in Section 8.5.3 (50% of the cleaning efforts given in the manufacturer's installation instructions for this application) and install the anchor. Load the anchor to failure with continuous measurement of load and displacement.

8.9 Sensitivity to mixing effort (Table 4.1, Test No. 2e; Table 4.2, Test No. 2e; Table 4.3, Test No. 2f; Table 4.4, Test No. 2f):

8.9.1 Purpose: These installation safety tests are used to assess the sensitivity of the adhesive material to mixing effort. These tests are required only for those anchor systems where the mixing of the adhesive material is substantially controlled by the installer. Such cases include:

a. systems that require components to be mixed until a color change is effected throughout the adhesive material;
b. systems that require the adhesive materials to be mixed with recommended equipment for a specific duration;
c. systems that require that the adhesive materials be mixed with a repetitive mixing operation a specific number of times.

8.9.1.1 These tests are not required for cartridge systems that employ static mixing nozzles or for capsule anchor systems.

8.9.2 General test conditions: Perform confined tension tests in uncracked concrete.

8.9.2.1 Exception: Tests on torque-controlled adhesive anchors shall be unconfined tension tests in cracked concrete.

8.9.3 Conduct tests as required to establish the required time for full mixing using standard mixing equipment. Reduced mixing effort shall be achieved by decreasing the mixing time or number of mixing operations required for full mixing by 25%. Load the anchor to failure with continuous measurement of load and displacement.

8.10 Sensitivity to reduced installation effort (Table 4.3, Test No. 2a; Table 4.4, Test No. 2a):

8.10.1 Purpose: These installation safety tests are intended to determine the sensitivity of torque-controlled anchors to adverse installation conditions.

8.10.2 General test conditions: Perform unconfined tension tests in cracked concrete.

8.10.3 Perform hole cleaning in accordance with manufacturer's published installation instructions.

8.10.4 Install the anchor with setting torque $T = 0.5T_{inst}$.

8.10.5 Load the anchor to failure with continuous measurement of load and displacement.

8.11 Sensitivity to installation in water-saturated concrete (Table 4.1, Test No. 2f; Table 4.2, Test No. 2f):

8.11.1 Purpose: These optional installation safety tests are used to independently assess the sensitivity of the adhesive material to applications in water-saturated concrete where the anchor category is to be determined in accordance with

8.11.2 Table **11.5**.

8.11.3 General test conditions: Perform tests in accordance with Section 8.6, however, hole cleaning shall be conducted in accordance with the manufacturer's published installation instructions.

8.12 Sensitivity to installation in a water-filled hole in saturated concrete (Table 4.1, Test No. 2g; Table 4.2, Test No. 2g):

8.12.1 Purpose: These optional installation safety tests are used to independently assess the sensitivity of the adhesive material to applications in water-filled hole in saturated concrete for cases where the anchor category is to be determined in accordance with

8.12.2 Table **11.5**.

8.12.3 General test conditions: Perform tests in accordance with Section 8.7, however, hole cleaning shall be conducted in accordance with the manufacturer's printed installation instructions.

8.13 Sensitivity to installation in submerged concrete (Table 4.1, Test No. 2h; Table 4.2, Test No. 2h):

8.13.1 Purpose: These optional installation safety tests are used to assess the sensitivity of the adhesive material to applications in submerged concrete where the anchor category is to be determined in accordance with

8.13.2 Table **11.5**.

8.13.3 General test conditions: Perform tests in accordance with Section 8.8; however, hole cleaning shall be conducted in accordance with the manufacturer's published installation instructions.

8.14 Sensitivity to crack width, low-strength concrete (Table 4.2, Test No. 3; Table 4.3, Test No. 3; Table 4.4, Test No. 3):

8.14.1 Purpose: These reliability tests are used to assess the sensitivity of the anchor system installed in low-strength concrete to a wide crack in the concrete passing through the anchor location.

8.14.2 General test conditions: Perform tension tests in cracked concrete. Tests on adhesive anchors shall be confined tension tests. Tests on torque-controlled adhesive anchors shall be unconfined tension tests.

8.14.2.1 Initiate the crack in the test member and install the anchor at the crack location so that the axis of the anchor lies approximately in the plane of the crack. Visually confirm the correct location of the crack in the drilled hole prior to installing the anchor in accordance with Section 5.4.2. Open the crack by the specified value Δw. Perform a confined tension test to failure with continuous measurement of load, displacement, and crack width.

8.15 Sensitivity to crack width, high-strength concrete (Table 4.2, Test No. 4; Table 4.3, Test No. 4; Table 4.4, Test No. 4):

8.15.1 Purpose: These reliability tests are used to assess the sensitivity of the anchor system installed in high-strength concrete to a wide crack in the concrete passing through the anchor location.

8.15.2 General test conditions: Perform tension tests in cracked concrete. Tests on adhesive anchors shall be confined tension tests. Tests on torque-controlled adhesive anchors shall be unconfined tension tests.

8.15.2.1 Initiate the crack in the test member and install the anchor at the crack location so that the axis of the anchor lies approximately in the plane of the crack. Visually confirm the correct location of the crack in the drilled hole prior to installing the anchor in accordance with Section 5.4.2. Open the crack by the specified value Δw. Perform a confined tension test to failure with continuous measurement of load, displacement, and crack width.

8.16 Sensitivity to crack width cycling (Table 4.2, Test No. 5; Table 4.3, Test No. 5; Table 4.4, Test No. 5):

8.16.1 Purpose: These reliability tests are performed to evaluate the performance of anchors located in cracks whose width is cycled.

8.16.2 General test conditions:

8.16.2.1 Perform crack cycling tests as unconfined tension tests in cracked concrete. Tests for residual capacity following crack cycling are confined tension tests performed in cracked concrete.

8.16.2.1.1 Exception: Tests for residual capacity on torque-controlled adhesive anchors shall be unconfined tension tests in cracked concrete

8.16.2.2 Prior to installing anchors in the test member, loading cycles as required to initiate crack opening and closing may be applied to the test member in order to stabilize the relationship between crack width and applied load. Loading shall not exceed the elastic limit of the test member. With the test member unloaded, install the anchor in a closed (hairline) crack that is sufficiently planar to ensure that the crack will approximately bisect the anchor location over the extent of the anchor load transfer zone. Visually verify the positioning of the anchor in the crack, e.g., by means of a boroscope or similar device. Install the anchor perpendicular to the surface of the test member and in accordance with Section 5.4 and test in accordance with Section 5.7.4 and this section. After installation of the anchor but before the anchor is loaded, subject the test member to loading as required to open the crack width by Δw_1 = 0.012 in. (0.3 mm) where Δw_1 is additive to the initial width of the crack after installation of the anchor but before loading of the anchor. Following application of load to the anchor sufficient to remove any slack in the loading mechanism, begin recording the anchor displacement and increase the tension load on the anchor to N_w as given by Eq. 8.1. Apply the load in accordance with Section 5.7.3.1 (unconfined).

$$N_w = 0.3 \cdot N_{k,i} \left(\frac{f_{c,test}}{f_{c,test,2}} \right)^n \quad \text{lb (N)} \qquad \text{Eq. 8.1}$$

where

$N_{k,i}$ = characteristic resistance as determined from reference service-condition tests in low-strength cracked concrete as follows: Table 4.2, Test No. 11c, Table 4.3, Test No.11c or Table 4.4, Test No. 10c, lb (N).

$f_{c,test}$ = concrete compressive strength as measured at the time of testing, psi (MPa).

$f_{c,test,2}$ = concrete compressive strength corresponding to the tests used to establish $N_{k,i}$, psi (MPa).

n = normalization exponent determined in accordance with Section 11.1.

8.16.2.3 While maintaining the static load on the anchor within 5% of N_w, cyclically load the test member as required to cause the crack width to alternate continuously between Δw_1 and the lower crack width limit Δw_2 =

0.004 in. (0.1 mm) where Δw_2 is additive to the initial width of the crack as measured after installation of the anchor but prior to loading of the anchor. Open and close the crack 1,000 times at a maximum frequency of approximately 0.2 Hz. The crack width test requirements are illustrated in Figure 8.1. During crack cycling, adjustment of the force required to maintain the crack opening width Δw_1 constant shall be permitted. The minimum load applied to the test member shall be held constant during the crack cycling portion of the test. The crack opening width Δw_2 shall be permitted to increase (see Figure 8-1); however, the difference $\Delta w_1 - \Delta w_2$ shall be maintained as not less than 0.004 in. (0.1 mm) for the duration of the crack cycling portion of the test. During the test, the amplitude of the load applied to the test member shall be adjusted as required to maintain a minimum differential $\Delta w_1 - \Delta w_2$ of 0.004 in. (0.1 mm). This may result in an increase in the crack width Δw_1 beyond 0.012 in. (0.3 mm) for part of the crack cycling portion of the test.

8.16.2.4 Measure the load-displacement relationship up to load N_w. At load N_w measure the displacements of the anchor and the crack-opening widths Δw_1 and Δw_2, either continuously or at least after 1, 2, 5, 10, 20, 50, 100, 200, 500, and 1000 cycles of crack opening and closing.

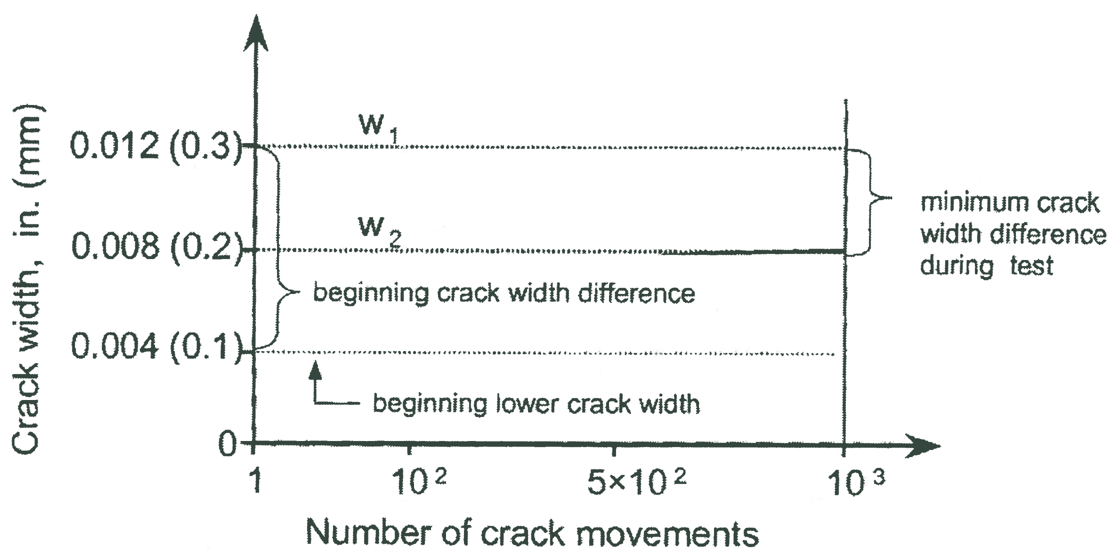


Fig. 8-1—Crack-width requirements for crack cycling

8.16.2.5 Following completion of the crack cycling portion of the test, unload the anchor, record the anchor displacement, open the crack width to Δw = 0.012 in. (0.3 mm) and perform a tension test of the anchor to failure with continuous measurement of load and displacement.

8.17 Sensitivity to freezing and thawing (Table 4.1, Test No. 3; Table 4.2, Test No. 6; Table 4.3, Test No. 6; Table 4.4, Test No. 6):

8.17.1 Purpose: These reliability tests are performed to evaluate the performance of anchors under freeze/thaw conditions.

8.17.2 General test conditions: Perform sustained tension tests in uncracked concrete, followed by confined tension tests to failure.

8.17.2.1 The test member shall consist of a cube or cylinder with side length (or diameter) 8 inches ≤ ℓ_{side} ≤ 12 inches (200 mm ≤ ℓ_{side} ≤ 300 mm) for anchor diameters 1/2 to 5/8 inches (12.7 to 15.9 mm). For anchor diameters d greater than 5/8-inch (16 mm), the test member shall have side length 15d ≤ ℓ_{side} ≤ 25d. The dimensions of the test member shall be chosen to avoid splitting of the test member during the conduct of the test. Freeze-thaw resistant concrete shall be permitted to be used. Restraint of the test member as required to prevent splitting shall be permitted. Where such restraint is used (e.g., steel cylinder), the dimensions of the specimen may be reduced.

8.17.2.2 Install and cure anchors at standard temperature.

8.17.2.3 Cover the top surface of the test member, within a minimum 3-inch (76 mm) radius from the center of the test anchor, with tap water maintaining a minimum of 1/2-inch (12.7 mm) depth throughout the test. All other exposed surfaces shall be sealed to prevent evaporation of water. Load the anchor with a constant tension load $N_{sust,ft}$ given by Eq. 8.2, to be maintained throughout the test.

$$N_{sust,ft} = 0.55 \cdot \overline{N}_{o,i} \left(\frac{f_{c,test}}{f_{c,test,i}} \right)^n \text{ lb (N)} \qquad \text{Eq. 8.2}$$

Where

$\overline{N}_{o,i}$ = mean tension capacity as determined from reference service-condition tests in high-strength concrete as follows: Table 4.1, Test No. 7b, Table 4.2, Test No. 11b, Table 4.3, Test No. 11b or Table 4.4, Test No. 10b, whereby results that are less than 85 percent of the mean value shall be excluded from the determination of the mean, i.e., the mean shall be re-calculated with the remaining results, lb (N)

$f_{c,test}$ = concrete compressive strength as measured at the time of testing, psi (MPa).

$f_{c,test,i}$ = concrete compressive strength corresponding to the tests used to establish $\overline{N}_{o,i}$, psi (MPa).

n = normalization exponent determined in accordance with Section 11.1.

8.17.2.4 Carry out 50 freeze/thaw cycles as follows:

1. Maintain load at $N_{sust,ft}$ throughout the freeze/thaw test.

2. Raise the temperature of the chamber within 1 hour to +68°F ± 5°F (+20°C± 2°C).
3. Maintain the chamber at +68°F ± 5°F (+20°C± 2°C) for an additional 7 hours.
4. Lower the temperature of the chamber to -4°F ± 5°F (-20°C± 2°C) within 2 hours.
5. Maintain the chamber temperature at -4°F ± 5°F (-20°C± 2°C) for an additional 14 hours.

8.17.2.5 The displacements shall be measured during the temperature cycles.

8.17.2.6 If the test is interrupted, the samples shall always be stored at a temperature of -4°F ± 5°F (-20°C± 2°C) between cycles.

8.17.2.7 After the completion of 50 cycles conduct a confined tension test at standard temperature.

8.18 Sensitivity to sustained loading at standard and maximum long-term temperature (Table 4.1, Test No. 4; Table 4.2, Test No. 7; Table 4.3, Test No. 7; Table 4.4, Test No. 7):

8.18.1 Purpose: These reliability tests are performed to evaluate the performance of anchors under sustained loads at standard temperature and maximum long-term temperature.

8.18.2 General test conditions:

8.18.2.1 Perform sustained tension tests in uncracked concrete, followed by confined tension tests to failure.

8.18.2.2 Install and cure anchors at standard temperature.

8.18.2.3 Tests shall be conducted at standard and long-term test temperatures corresponding to the desired temperature categories in accordance with Table 9.1.

8.18.2.4 Temperature control shall be permitted to be maintained via thermocouples in the concrete test member. Embed thermocouples a maximum of 4-1/2 inches (114 mm) from the surface of the concrete into which the anchors are to be installed. The thermocouples shall be either cast in the concrete or positioned in holes drilled in the cured test member. Drilled holes for thermocouples shall have a maximum nominal diameter of 1/2 inches (12.7 mm) and shall be sealed in such a manner that the temperature readings reflect the concrete temperature.

8.18.2.4.1 Exception: The use of thermocouples is not required if it can be experimentally demonstrated that the test procedure will consistently produce test member temperatures in accordance with the target temperatures. The test procedure will include monitoring of test chamber temperature at maximum one-hour intervals.

8.18.2.5 Each test shall have a minimum duration of 42 days.

8.18.3 Tests at standard temperature:

8.18.3.1 Within 48 hours of when the curing period has elapsed, the temperature of the test member shall be adjusted until the temperature as recorded by the embedded thermocouples is stabilized at the target temperature. A tension preload not exceeding the lesser of 5% of $N_{sust,lt}$ or 300 pounds (1334 N) shall be applied to the anchor prior to zeroing displacement readings. Then increase the load on the anchor to a constant tension load $N_{sust,lt}$ as given by Eq. 8.3.

$$N_{sust,lt} = 0.55 \cdot \overline{N}_{o,i} \left(\frac{f_{c,test}}{f_{c,test,i}} \right)^n \text{ lb (N)} \qquad \text{Eq. 8.3}$$

where:

$\overline{N}_{o,i}$ = mean tension capacity as determined from reference service-condition tests in low-strength concrete as follows: Table 4.1, Test No. 7a, Table 4.2, Test No.11a, Table 4.3, Test No. 11a or Table 4.4, Test No. 10a, whereby results that are less than 85 percent of the mean value shall be excluded from the determination of the mean, i.e., the mean shall be re-calculated with the remaining results, lb (N)

$f_{c,test}$ = concrete compressive strength as measured at the time of testing, psi (MPa).

$f_{,ctest,i}$ = concrete compressive strength corresponding to the tests used to establish $\overline{N}_{o,i}$, psi (MPa).

n = normalization exponent determined in accordance with Section 11.1.

8.18.3.2 Maintain a minimum load of $N_{sust,lt}$ and maintain temperature at standard temperature.

8.18.3.3 Anchor displacement shall be recorded for the duration of the test. The frequency of monitoring displacements shall be chosen so as to demonstrate the characteristics of the anchor. As displacements are greatest in the early stages, the monitoring frequency should be high initially and may be reduced over time. As an example, the following monitoring schedule would be acceptable:

a. During the first hour: every 10 minutes
b. During the next 6 hours: every hour
c. During the next 10 days: every day
d. Thereafter: every 5-10 days

8.18.3.4 Temperatures in the test chamber may vary by $\pm$ 6°F (3°C) due to day/night and seasonal effects but the required test chamber temperature shall be achieved as an average over the test period. The concrete test member temperature shall be recorded at maximum one-hour intervals. If thermocouples are not used (see Section 8.18.2.4.1), the temperature in the test chamber shall be recorded at maximum one-hour intervals.

8.18.3.4.1 Alternatively, the concrete test member temperature shall be permitted to be recorded at maximum 24-hour intervals provided that the temperature of the conditioning chamber necessary to maintain the target test member temperature is recorded at maximum one-hour intervals.

8.18.3.5 If the concrete test member temperature falls below the minimum target temperature (including tolerances) for more than 24 hours, the test duration shall be extended by the length of time for which the temperature was below the target minimum.

8.18.3.6 At the conclusion of the sustained loading portion of the test, conduct a confined tension test to failure at standard temperature with continuous measurement of load and displacement.

8.18.4 Tests at long-term elevated temperature:

8.18.4.1 It is required to perform the tests in a concrete test member made from the same batch as the test member used for the tests at short-term elevated temperature.

8.18.4.2 Within 48 hours of when curing period has elapsed, the temperature of the test member shall be increased until the temperature as recorded by the embedded thermocouples is stabilized at the target temperature. Raise the temperature of the test chamber to the maximum long-term temperature (categories A and B according to Table 9.1) at a rate of approximately 35°F (20°C) per hour. A tension preload not exceeding the lesser of 5% of $N_{sust,lt}$ or 300 pounds (1334 N) shall be applied to the anchor prior to zeroing displacement readings. Then increase the load on the anchor to a constant tension load $N_{sust,lt}$ as given by Eq. 8.3 multiplied by 0 α_{lt} as given in Eq. 11.33.

8.18.4.3 Maintain load $N_{sust,lt}$ and maintain temperature at the maximum long-term temperature. For tolerances on the temperature of the test chamber and the frequency of displacement monitoring, see Section 8.18.3.

8.18.4.4 To check the remaining load capacity after the sustained load test, unload the anchor and carry out a confined tension test at the maximum long-term temperature.

8.19 Sensitivity to installation direction (Table 4.1, Test No. 5; Table 4.2, Test No. 8; Table 4.3, Test No. 8; Table 4.4, Test No. 8):

8.19.1 Purpose: These reliability tests are performed to evaluate the performance of adhesive anchors installed horizontally and overhead.

8.19.2 General test conditions: Perform confined tension tests in uncracked concrete. Conduct tests on all-thread anchors that have been installed in accordance with manufacturer's published installation instructions.

8.19.3 Separate test series shall be performed with anchors installed horizontally and overhead. Perform tension tests to failure with continuous measurement of load and displacement.

8.20 Torque tests (Table 4.1, Test No. 6; Table 4.2, Test No. 9; Table 4.3, Test No. 9; Test No. 9, Table 4.4):

8.20.1 Purpose: These reliability tests shall be used to establish the maximum level of torque that can be applied to the installed anchor without inducing tension yield of the anchor element. These reliability tests may also be performed to establish whether anchors of one design but fabricated with different production methods or materials or having different bolt head configurations exhibit the same performance. See Sections 4.5 and 4.6.

8.20.2 General test conditions: Fig. 8.2 shows the test setup. The fixture shall contain all of the elements shown. The double-sided abrasive paper shall have sufficient roughness to prevent rotation of the washer relative to the test fixture during the application of torque. Other methods of preventing rotation of the washer shall be permitted provided that it can be shown that they do not affect the performance of the anchor.

8.20.3 Apply increasing torque and record the torque and corresponding induced tension in the anchor bolt. The washer shall not turn during the application of torque.

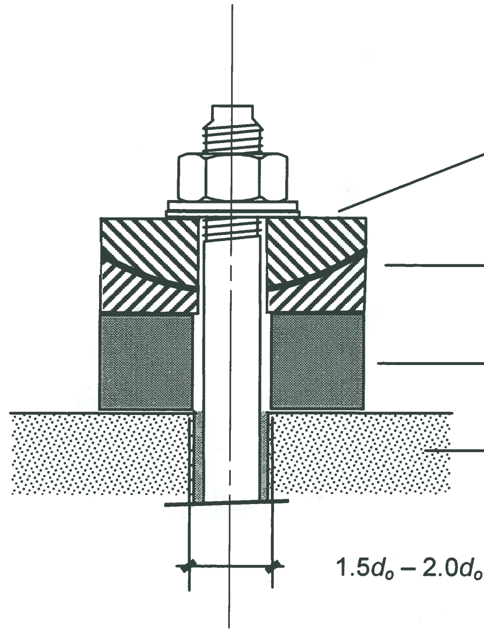


Fig. 8.2 – Torque test setup

8.21 Slip force tests (Table 4.3, Test No. 10a):

8.21.1 Slip force tests shall be conducted on torque-controlled adhesive anchors in cracked concrete to estimate the tension force corresponding to loss of adhesion between the anchor element and the adhesive. A significant and sudden change in slope of the load-displacement curve or a sudden increase in the expansion force (as measured on pre-split test blocks) may be assumed to indicate loss of adhesion. An acceptable method for conducting the slip force tests is given in Section 8.21.1.1.

8.21.1.1 Install the anchor in accordance with the manufacturer's printed installation instructions in a hairline crack; however, do not apply the recommended installation torque. Open the crack by Δw and perform a confined tension test to failure with continuous measurement of load and displacement at the unloaded end of the anchor element (see Fig.8.3). The displacement of the anchor element relative to the concrete as measured at the unloaded end of the anchor element shall be permitted to be used to estimate the force corresponding to loss of adhesion (slip force). Other methods shall also be permitted.

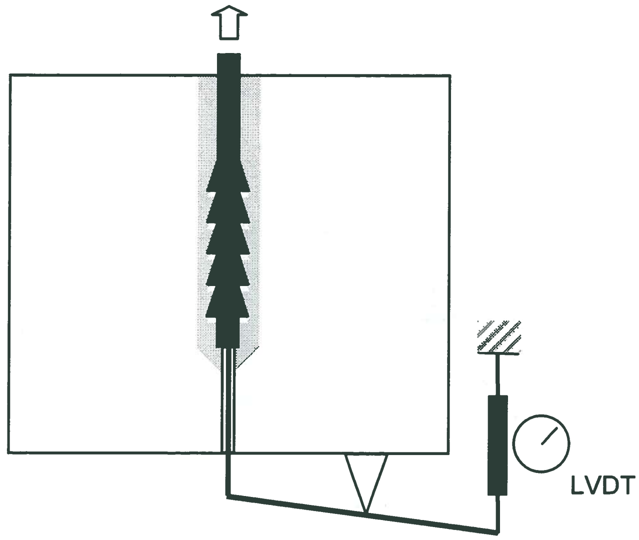


Fig. 8.3 – Slip force test setup

8.22 Bond force tests (Table 4.3, Test No. 10b):

8.22.1 Bond force tests shall be conducted in cracked concrete with the adhesive used for torque-controlled adhesive anchors to estimate the tension force corresponding to loss of adhesion between the adhesive and the concrete under the most adverse conditions anticipated by this criteria. For these tests, Unified National Coarse (UNC) threaded rod of an equivalent nominal diameter shall be substituted for the anchor element specified by the manufacturer, and no installation torque shall be applied. The adhesive shall otherwise be installed in accordance with the manufacturer's printed installation instructions; however, the hole cleaning and condition shall correspond to the installation safety test included in the test program (see Sections 8.5, 8.6, 8.7 and 8.8) that represents the most adverse condition for the adhesive.

9.0 SERVICE-CONDITION TESTS

9.1 Purpose:

9.1.1 The purpose of the service-condition tests is to determine the basic data required to predict the performance of the anchor under service conditions.

9.2 Required tests:

9.2.1 Required service-condition tests are given in Table 4.1 for adhesive anchors to be qualified for use in uncracked concrete only and in Table 4.2 for adhesive anchors to be qualified for use in both uncracked and cracked concrete. The requirements for torque-controlled adhesive anchors are given in Table 4.3 and Table 4.4

9.3 Conduct of tests:

9.3.1 Prepare test members, install anchors and test in accordance with Section 5.0 unless otherwise noted.

9.3.2 Perform tests in dry concrete.

9.3.3 Perform tests with air, concrete and anchor at standard temperature unless otherwise noted.

9.4 Tension tests in uncracked and cracked concrete (Table 4.1, Test No. 7a and 7b; Table 4.2, Test No. 11a, 11b, 11c, and 11d; Table 4.3, Test No. 11a, 11b, 11c, and 11d; Table 4.4, Test No. 10a, 10b, 10c, and 10d):

9.4.1 Purpose: These tests are used to establish the bond resistance of the anchor system.

9.4.2 Conduct of tests: Perform unconfined service-condition tension tests in accordance with Section 5.7.

9.4.2.1 It shall be permitted to perform the service condition tension tests described in Table 4.1, Test Nos. 7a and 7b and Table 4.2, Test Nos. 11a, 11b, 11c and 11d as confined tests if the evaluation for $\tau_{k,cr}$ is performed in accordance with Section 11.3.5.3.3.

9.5 Tension tests at elevated temperature (Table 4.1, Test No. 8a; Table 4.2, Test No. 12a; Table 4.3, Test No. 12a; Table 4.4, Test No. 11a):

9.5.1 Purpose: These service-condition tests are used to assess the sensitivity of the adhesive material to applications in concrete with elevated temperature.

9.5.2 General test conditions: Conduct static tension tests at long-term and short-term concrete temperatures corresponding to the desired temperature category as given in Table 9.1. It shall be permitted to obtain qualification at multiple temperature categories.

Table 9.1 – Minimum test temperatures [1]

Temperature category	Long-term test temperature		Short-term test temperature	
	°F	°C	°F	°C
A	110	50	180	80
B	≥ 0.60 x (short-term test temp)	≥ 0.60 x (short-term test temp)	≥ 110	≥ 50

[1] All test temperatures have a minus tolerance of 0 degrees.

9.5.2.1 Conduct confined tension tests in uncracked concrete.

9.5.2.2 Temperature control shall be maintained via thermocouples in accordance with Section 8.18.2.4. Alternatively, it shall be permitted to correlate the chamber temperature with the test member internal temperature by separate investigations, and to control the chamber temperature for the elevated temperature tests.

9.5.2.3 Anchors shall be qualified for one or both of the temperature categories A and B as given in Table 9.1. For temperature categories A, perform tests at the short-term and long-term test temperatures. Install and test a minimum of five anchors for each temperature data point. For temperature category B, install and test a minimum of five anchors at the following temperatures: at standard temperature, at the long-term and short-term test temperatures, and at a minimum of two intermediate temperatures between the long-term and short-term temperatures with a maximum increment of 35°F (20°C). If the difference between the standard temperature and the selected short-term test temperature is less than 35°F (20°C), then testing at intermediate temperatures is not required.

9.5.2.4 All anchors are to be installed and cured at standard temperature. Following the recommended cure period, heat and maintain the test members at the desired temperature for a minimum of 24 hours. Remove each test member from the heating chamber and conduct a confined tension test to failure with continuous measurement of load and displacement before the temperature of the test member falls below the target temperature.

9.6 Tension tests with decreased installation temperature (Table 4.1, Test No. 8b; Table 4.2, Test No. 12b; Table 4.3, Test No. 12b; Table 4.4, Test No. 11b):

9.6.1 Purpose: These optional service-condition tests are used to assess the sensitivity of the adhesive material to installation in concrete having reduced temperature.

9.6.2 General test conditions:

9.6.2.1 Tests are confined tension tests performed in uncracked concrete for anchors to be installed in concrete having a temperature less than 50°F (10°C). Concrete test members shall have maximum dimensions 30 in. by 18 in. by 12 in. (760 mm by 460 mm by 300 mm). Alternatively, a 12-in. (300 mm) high cylinder with maximum diameter 13 in. (330 mm) may be used. Perform tests as follows: (a) Prior to installation, condition the anchor rod and test member to the target temperature (i.e., the lowest installation temperature recommended by the manufacturer) and maintain that temperature for a minimum of 24 hours. (b) Install the anchors in concrete test members and allow them to cure at the stabilized temperature for the cure time according to the manufacturer's printed installation instructions. (c) Immediately thereafter, remove the test members from the cooling chamber and tension test the anchors in order to assure the test members remain at the conditioned temperature. A thermocouple inserted into the test member may be used to confirm the temperature at the time of testing.

9.6.2.2 When anchors are recommended for installation in concrete temperatures below 40°F (5°C), install and test a minimum of five (5) anchors as follows: (a) Prior to installation, condition the anchor rod and test member to the target temperature (i.e., the lowest installation temperature recommended by the manufacturer) and maintain that temperature for a minimum of 24 hours. (b) Install the anchors in accordance with the manufacturer's printed installation instructions and allow them to cure at the stabilized target temperature for the cure time according to the manufacturer's printed installation instructions. (c) Immediately thereafter, apply a constant tension load $N_{sust,ft}$ as given by Eq. 8.3. (d) Raise the temperature of the test chamber at a constant rate to standard temperature over a period of 72 to 96 hours while monitoring the displacement response for each anchor. A thermocouple inserted into the test member may be used to confirm the temperature of the test members during the test. (e) Once the test member attains standard temperature, conduct a confined tension test to failure with continuous measurement of load and displacement.

9.7 Establishment of cure time at standard temperature (Table 4.1, Test No. 8c; Table 4.2, Test No. 12c; Table 4.3, Test No. 12c; Table 4.4, Test No. 11c):

9.7.1 Purpose: These service-condition tests are used to establish the minimum curing time of the adhesive material for the anchor to achieve full tension capacity.

9.7.2 General test conditions: Tests are confined tension tests performed in uncracked concrete. Tests are conducted on anchors installed according to manufacturer's printed installation instructions at standard temperature and allowed to cure for the minimum curing time according to the manufacturer's printed installation instructions, and on anchors installed in the same way and allowed to cure for a time according to the manufacturer's printed installation instructions plus 24 hours.

9.8 Durability assessment (Table 4.1, Test Nos. 9a and 9b; Table 4.2, Test Nos. 13a and 13b; Table 4.3, Test Nos. 13a and 13b; Table 4.4, Test Nos. 12a and 12b):

9.8.1 Purpose: These service-condition tests are used to assess the response of the adhesive material to attack by environmental aggressors. The durability of the adhesive material shall be verified by slice tests. With slice tests, the sensitivity of installed anchors to different environmental exposures can be assessed. Testing for exposure to high alkalinity in accordance with Section 9.8.2.3.1 is required. Testing for exposure to sulfur dioxide in accordance with Section 9.8.2.3.2 is optional.

9.8.2 General test conditions:

9.8.2.1 Conduct tests on 1/2-inch-diameter (12.7 mm), all-thread anchors or the smallest nominal diameter if it is larger than $^1/_2$ in. (12.7 mm). Anchors shall be embedded into cylindrical concrete test members having a minimum diameter of 6 inches (150 mm). For testing of torque-controlled adhesive anchors, all-thread rod shall be substituted for the anchor element specified by the manufacturer. The concrete test members shall be cast in lengths of steel or plastic pipe having a wall thickness as required to prevent splitting of the slices during punch testing. All test members shall originate from the same concrete batch. Install the anchors along the central axis of the concrete test members according to the manufacturer's printed installation instructions. For all tests in sulfur dioxide, the embedded part shall be fabricated from austenitic stainless steel. After curing of the adhesive the concrete cylinders in which the anchors are installed shall be sawn with a diamond saw into 1-3/16 inch +/- 1/8 in. (30 mm +/- 3 mm) thick slices in such a manner that the resulting slices are not noticeably damaged. The slices shall be oriented perpendicular to the anchor axis and shall consist of the concrete, adhesive material and anchor element. The top slice shall be discarded. Prepare a minimum of ten slices for each environmental exposure to be investigated as well as ten reference slices subjected to standard climate conditions.

9.8.2.2 Storage of reference slices: The slices shall be stored under normal climate conditions (dry / standard temperature / relative humidity 50 ± 5%) for a minimum of 2,000 hours.

9.8.2.3 Storage of slices under aggressive environmental exposure: Ten slices each shall be stored under the following environmental exposures.

9.8.2.3.1 High alkalinity: The slices are stored under standard climate conditions in a container filled with an alkaline fluid (pH = 13.2). All slices shall be completely covered for a minimum of 2,000 hours. The alkaline fluid is produced by mixing water with KOH (potassium hydroxide) powder or tablets until the pH-value of 13.2 is reached. A mean alkalinity value of pH = 13.2 ± 0.2 shall be maintained during the storage. If the measured alkalinity falls below 13.0, the total length of time during which the pH value falls below 13.0 shall be added to the test duration and shall not be included in the calculation of the mean alkalinity value. The pH-value shall be checked and monitored at regular intervals.

9.8.2.3.2 Sulfur dioxide: Tests shall be performed according to EN ISO 6988 (Kesternich Test); however, the theoretical sulfur dioxide concentration shall be 0.67% at the beginning of a cycle, corresponding to 2 dm^3 of SO_2 for a test chamber volume of 300 dm^3. At least 80 cycles shall be conducted.

9.8.3 Punch tests: After the storage time has elapsed, the thickness of the slices shall be measured and the slices shall be tested in a test apparatus that permits the anchor element of the slice to be punched through the slice while restraining the surrounding concrete (see Fig. 9.1). The loading punch shall act centrally on the anchor element. The peak load for each test shall be recorded. Results from slices that split during the punch test shall be discarded. The bond strength $\tau_{dur,i}$ for each punch test shall be evaluated using Eq. 9.1

$$\tau_{dur,i} = \frac{N_{u,i}}{\pi \cdot d \cdot h_{sl}} \quad \text{psi (MPa)} \qquad \text{Eq. 9.1}$$

where:

h_{sl} = measured thickness of the slice i, in. (mm).

d = anchor diameter, in. (mm).

$N_{u,i}$ = measured axial load corresponding to failure of slice i, lb (N).

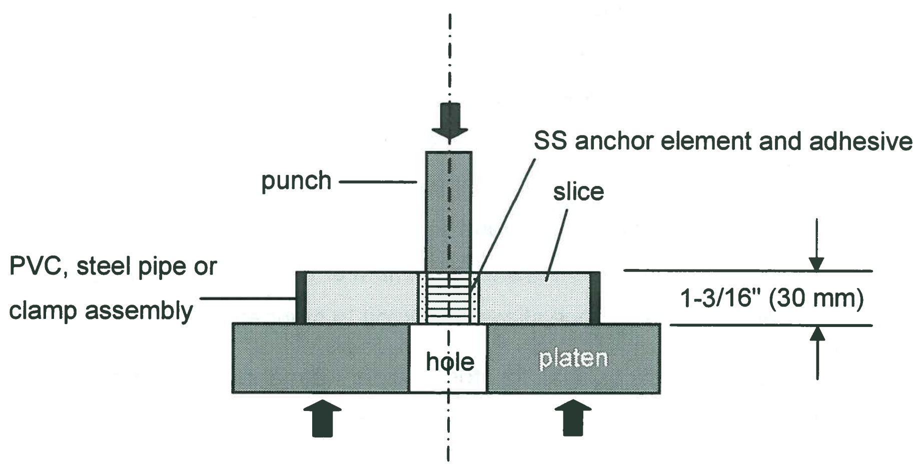


Fig. 9.1 – Punch test

9.9 Verification of full concrete capacity in a corner (Table 4.1, Test No. 10; Table 4.2, Test No. 14; Table 4.3, Test No. 14; Table 4.4, Test No. 13):

9.9.1 Purpose: This test is performed to verify the critical edge distance c_{cr}, in test members with the minimum specified thickness for that anchor.

9.9.2 General test conditions: Perform tests on single anchors in uncracked, low-strength concrete located in the corner with equal edge distances of c_{cr}, and test member thickness, h_{min} as shown in Fig. 9.2.

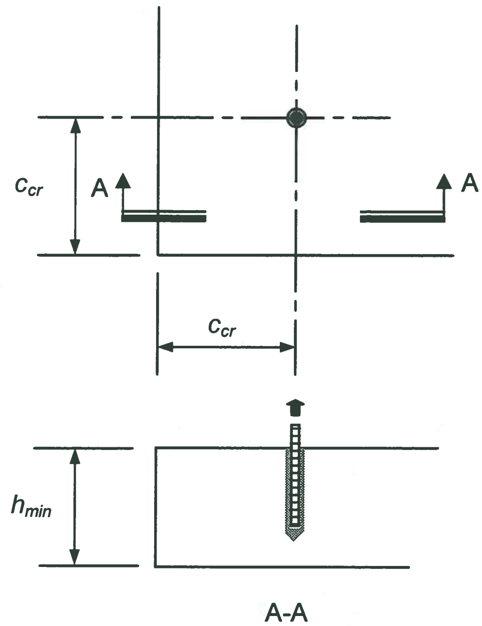


Fig. 9.2 – Corner test

9.10 Determination of minimum spacing and edge distance to preclude splitting (Table 4.1, Test No. 11; Table 4.2, Test No.15; Table 4.3, Test No. 15; Table 4.4, Test No. 14):

9.10.1 Purpose: This test is performed to verify for the s_{min} and c_{min} requested by the manufacturer that:

a. the concrete will not experience splitting failure during installation, and

b. the required tension capacity is achieved.

9.10.2 General test conditions: Test anchors in uncracked, low-strength concrete. Install two anchors at the minimum spacing, s_{min}, and the minimum edge distance, c_{min}, in test members with the minimum thickness, h_{min}, to be reported for the anchor. Place the two anchors in a line parallel to the edge of a concrete test element as shown in Fig. 9.3 at a distance of at least $3h_{ef}$ from other groups. Select s_{min}, c_{min}, and h_{min}, depending on the anchor characteristics.

9.10.2.1 Separate bearing plates shall be permitted to be used for each anchor to simplify the detection of concrete cracking. The distance to the edge of the bearing plate from the centerline of the corresponding anchor shall be three times the diameter d of the anchor being tested.

9.10.2.2 Calculate the expected mean tension failure load corresponding to the edge distance and spacing of the anchor group to be tested on the basis of the service-condition tests and taking into account the effects of reduced spacing and edge distance. If the average prestressing force corresponding to $T = 1.7T_{inst}$ exceeds the calculated mean tension failure load of the anchor group in uncracked concrete, perform a torque test in accordance with Section 9.10.2.3. Otherwise, perform a load test in accordance with Section 9.10.2.4.

9.10.2.3 Torque test: Torque the anchors alternately in increments of $0.2T_{inst}$. After each increment, inspect the concrete surface for cracks. Stop the test when splitting or steel failure prevents the torque from being increased further. For each test, record the torque at the formation of the first hairline crack at one or both anchors and the maximum torque that can be applied to the anchors.

9.10.2.4 Load test: Install the anchors according to the manufacturer's printed installation instructions using the minimum specified spacing and edge distances. Load the anchor group in tension to failure as an unconfined test.

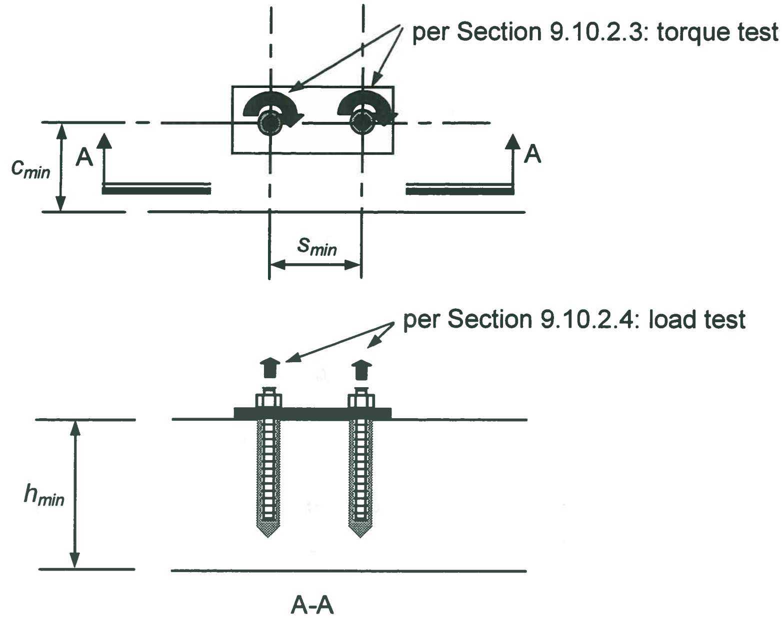


Fig. 9.3 – Test for minimum edge distance and minimum spacing

9.11 Tests to determine shear capacity of anchor elements with non-uniform cross-section (Table 4.1, Test No. 12; Table 4.2, Test No. 16; Table 4.3, Test No. 16; Table 4.4, Test No. 15):

9.11.1 Purpose: This test is performed to evaluate the shear capacity of anchors as governed by element shear failure in situations where the shear capacity cannot be reliably calculated.

9.11.2 General test conditions: For anchors having a cross-sectional area that is less than that of a threaded bolt of the same nominal diameter as the anchor within five anchor diameters of the shear failure plane, perform shear tests in uncracked concrete in accordance with ASTM E 488.

9.11.3 For anchors evaluated according to Table 4.2, Table 4.3, or Table 4.4, at the option of the manufacturer, shear tests shall be performed in cracked concrete with a crack width of 0.012 in. (0.3 mm) and with the shear load applied parallel to the crack.

9.12 Simulated seismic tension tests (Table 4.2, Test No. 17; Table 4.3, Test No. 17; Table 4.4, Test No. 16)

9.12.1 Purpose: These optional tests are intended to evaluate the performance of anchors in seismic tension, including the effects of cracks, and without edge effects. Qualification for seismic loading shall only be considered in the context of a cracked concrete test program in accordance with Table 4.2, Table 4.3, or Table 4.4.

9.12.2 General test conditions: Test each anchor diameter at embedments as specified in Table 4.2, Table 4.3, or Table 4.4. Install the anchor in a hairline crack in accordance with Section 5.4. If no torque is specified by the manufacturer's printed installation instructions, finger-tighten the anchor prior to testing. Test internally threaded anchors with the bolt specified by the manufacturer and report the bolt type in Table 12.3. Open the crack by Δw = 0.020 in. (0.5 mm) where Δw is additive to the width of the closed (hairline) crack after anchor installation. Subject the anchors to the sinusoidal-tension loads specified in Table 9.2 and Fig. 9.4 with a cycling frequency between 0.1 and 2 Hz, whereby N_{eq} is given by Eq. 9.2, N_m is given by Eq. 9.3, and N_i is given by Eq. 9.4.

$$N_{eq} = 0.5 \cdot \overline{N}_{o,i} \left(\frac{f_{c,test}}{f_{c,test,2}} \right)^n \quad \text{lb (N)} \qquad \text{Eq. 9.2}$$

Where

$\overline{N}_{o,i}$ = mean tension capacity from reference service-condition tension tests in low-strength cracked concrete as follows: Table 4.2, Test No. 11c, Table 4.3, Test No.11c or Table 4.4, Test No. 10c, lb (N).

$f_{c,test}$ = compressive strength of concrete used at time of testing, psi (MPa).

$f_{c,test,2}$ = concrete compressive strength corresponding to the tests used to establish $\overline{N}_{o,i}$, psi (MPa).

n = normalization exponent determined in accordance with Section 11.1.

$$N_m = \frac{N_{eq}}{2} \quad \text{lb (N)} \qquad \text{Eq. 9.3}$$

$$N_i = \frac{N_{eq} + N_m}{2} \quad \text{lb (N)} \qquad \text{Eq. 9.4}$$

9.12.2.1 Record the crack width, anchor displacement and applied tension load in accordance with Section 5.7.4. Following completion of the simulated seismic-tension cycles, open the crack to a width not less than the crack opening width as measured at the end of the cyclic test and load the anchor in tension to failure. Record the maximum tension load (residual tension capacity), the corresponding displacement, and plot the load-displacement response.

Table 9.2 – Required loading history for simulated seismic tension test

Load level	N_{eq}	N_i	N_m
Number of cycles	10	30	100

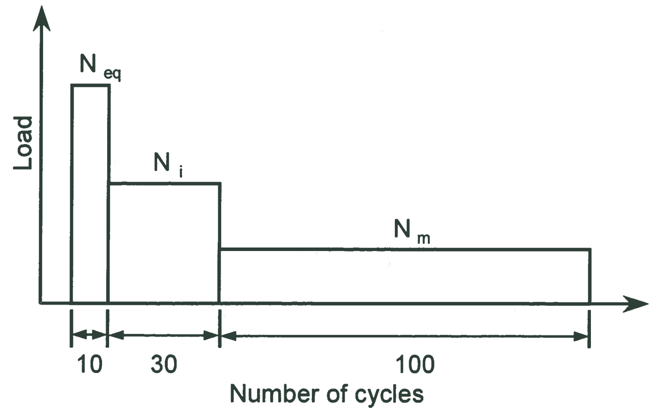


Fig. 9.4 – Required load history for simulated seismic tension test

9.13 Simulated seismic shear tests (Table 4.2, Test No. 18; Table 4.3, Test No. 18; Table 4.4, Test No. 17)

9.13.1 Purpose: These optional tests are intended to evaluate the performance of anchors subjected to seismic shear loads, including the effects of concrete cracking. Qualification for seismic loading shall only be considered in the context of a cracked concrete test program as given in Table 4.2, Table 4.3, or Table 4.4.

9.13.2 General test conditions: Test each anchor diameter at embedments as specified in Table 4.2, Table 4.3 or Table 4.4. Install the anchor in a hairline crack in accordance with Section 5.4. If no torque is specified by the manufacturer's printed installation instructions, finger-tighten the anchor prior to testing. Test internally threaded anchors with the bolt specified by the manufacturer and report the bolt type in Table 12.2 or Table 12.3. Open the crack by Δw = 0.020 in. (0.5 mm) where Δw is additive to the width of the initial (hairline) crack after anchor installation. Subject the anchors to the sinusoidal-shear loads specified in Table 9.3 and Fig. 9.5 with the shear load applied parallel to the direction of the crack, whereby V_{eq} is given by Eq. 9.5, V_m is given by Eq. 9.6, and V_i is given by Eq. 9.7.

$$V_{eq} = 0.5 \cdot \overline{V}_{o,i} \frac{f_{ut,test}}{f_{ut,test,2}} \quad \text{lb (N)} \qquad \text{Eq. 9.5}$$

where

$\overline{V}_{o,i}$ = mean shear capacity of anchors from reference service-condition tests in uncracked, low-strength concrete as follows: Table 4.2, Test No. 16, Table 4.3, Test No. 16, Table 4.4, Test No. 15, lb (N).

$f_{ut,test}$ = ultimate tensile strength of steel anchor elements used in seismic tests, psi (MPa).

$f_{ut,test,2}$ = ultimate tensile strength of steel anchor elements used in reference service-condition tests, psi (MPa).

$$V_m = \frac{V_{eq}}{2} \quad \text{lb (N)} \qquad \text{Eq. 9.6}$$

$$V_i = \frac{V_{eq} + V_m}{2} \quad \text{lb (N)} \qquad \text{Eq. 9.7}$$

9.13.2.1 If service-condition shear tests have not been performed, V_{eq} shall be permitted to be evaluated in accordance with Eq. 9.8.

$$V_{eq} = 0.35 \cdot A_{se} \cdot f_{ut,test} \quad \text{lb (N)} \qquad \text{Eq. 9.8}$$

9.13.2.2 The frequency of loading shall be between 0.1 and 2 Hz. To reduce the potential for uncontrolled slip during load reversal, the alternating shear loading shall be permitted to be approximated by the application of two half-sinusoidal load cycles at the desired frequency connected by a reduced-speed, ramped load as shown in Fig. 9.6.

9.13.2.3 Record the crack width, anchor displacement and applied shear load in accordance with Section 5.7.4. Plot the load-displacement history in the form of hysteresis loops.

9.13.2.4 Following completion of the simulated seismic-shear cycles, open the crack to a width not less than the crack opening width as measured at the end of the cyclic shear test and load the anchor in shear to failure. Record the maximum shear load (residual shear capacity), the corresponding displacement, and plot the load-displacement response.

Table 9.3 – Required loading history for simulated seismic shear test

Load level	$\pm V_{eq}$	$\pm V_i$	$\pm V_m$
Number of cycles	10	30	100

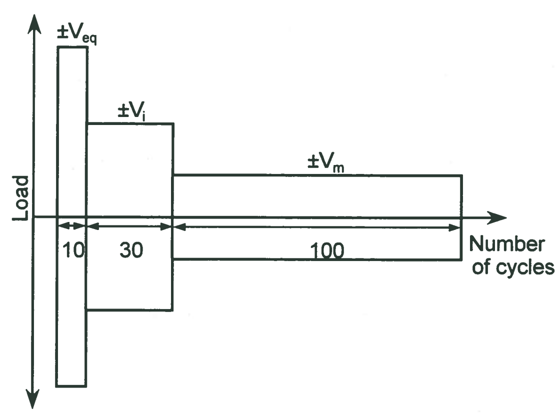


Fig. 9.5 – Required load history for simulated seismic shear test

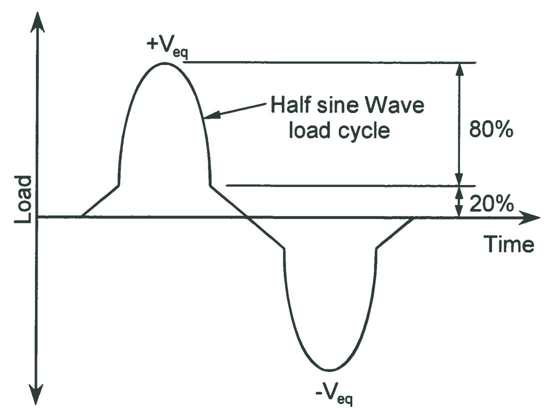


Fig. 9.6 – Permitted approximation of seismic shear cycle

10.0 SUPPLEMENTAL TESTS

10.1 Round-robin tests (Table 4.1, Test No. 13; Table 4.2, Test No. 19)

10.1.1 Purpose: These round-robin tests are performed in order to calibrate adhesive anchor test results for regional variations in concrete.

10.1.2 General test conditions: Perform tension tests on anchor diameters and embedments as specified in Table 4.1 or Table 4.2. In all tension tests, steel failure shall be avoided.

10.1.3 Round-robin tension tests shall be performed by the laboratory of the Independent Testing and Evaluation Agency (primary laboratory) and three additional independent laboratories accredited for the testing of adhesive anchors in accordance with Section 13.0 (secondary laboratories).

10.1.3.1 Exception: In lieu of accreditation to perform testing and assessment in accordance with this criteria, the secondary laboratories shall be permitted to be accredited for the testing of anchors in accordance with ASTM E 488.

10.1.4 The three secondary laboratories shall be selected by the primary testing laboratory. All round-robin tests shall be conducted with ASTM A 193 B7 Unified National Coarse (UNC) threaded rod anchors. If steel failure occurs, the embedment depth shall be reduced for all round-robin tests. Anchor test specimens sampled in accordance with Section 5.1 shall be provided by the primary testing laboratory to the three additional laboratories. Where the primary laboratory uses data from more than one laboratory for the assessment of the service-condition tension capacity in low-strength concrete, each laboratory shall provide round-robin tests.

10.1.5 The four laboratories performing round-robin tests shall each be located in a different geographic region in North America, whereby the geographic regions shall be defined by time zone as follows: Region 1: Pacific Time Zone; Region 2: Mountain Time Zones, Region 3: Central Time Zone, Region 4: Eastern and Atlantic Time Zones. If the primary laboratory is located outside of North America, four secondary laboratories, each located in a different geographic region in North America, shall be selected by the primary laboratory and round-robin tests shall be provided by the secondary laboratories only. The aggregates used for the concrete shall be representative of typical concrete production in each laboratory's immediate geographic location.

10.1.6 For the purpose of the round-robin tests, each secondary laboratory shall cast an unreinforced concrete test member approximately 12-in. (300 mm) thick with minimum plan dimensions of 4 ft x 3 ft (1.2 m x 0.9 m) from normal weight concrete using a mix design formulated to have a measured strength of 3,000 psi ± 500 psi (20.7 MPa ± 3.4 MPa) at the time of testing. Mix designs shall be in accordance with Section 5.2.2. Cement shall be Type I in accordance with ASTM C 150. Aggregates shall be in accordance with Section 5.2.3. Test member strength shall be confirmed based on field cured cylinders in accordance with Section 5.3.3.2. No admixtures or other additives shall be used.

10.1.7 Anchors shall be installed in accordance with the manufacturer's printed installation instructions. A minimum of 5 unconfined tension tests to failure in uncracked concrete shall be performed in accordance with Section 5.7. If Eq. 10.1 is not fulfilled with the results of the unconfined tests, an additional 5 confined tests to failure at an embedment of $7d$ in uncracked concrete shall be performed in accordance with Section 5.7. Testing shall be performed within the concrete age interval of 28 to 56 days. A series of five replicate tests shall be performed.

$$k_m \leq 24 \quad \text{in., lb}$$

$$k_m \leq 10 \quad \text{N, mm} \qquad \text{Eq. 10.1}$$

where:

$$k_m = \frac{\bar{N}_u}{h_{ef}^{1.5}\sqrt{f_{c,test,i}}} \quad \text{in., lb [N, mm)}$$

$\bar{N}_u$ = mean ultimate tension load measured in unconfined round-robin tests

10.2 Tests to determine minimum member thickness (Table 4.1, Test No. 14; Table 4.2, Test No. 20; Table 4.3, Test No. 19; Table 4.4, Test No. 18)

10.2.1 Purpose: These optional tests are performed to check the minimum member thickness specified by the manufacturer.

10.2.2 General test conditions: Test anchor diameters and embedments as specified in Table 4.1, Table 4.2, Table 4.3, or Table 4.4.

10.2.2.1 A minimum of 10 installation tests shall be performed for the maximum embedment depth h_{ef} associated with each anchor diameter to demonstrate that drilling of the hole and installation (e.g., setting, torquing) of the anchor does not result in cracking or breakthrough of the concrete test member. A test shall consist of drilling the hole, setting the anchor, and inspecting the test member for visible concrete cracking or spalling. For the purpose of these tests, the test member (slab, beam) shall be supported with a shear span length (distance from anchor to support) not less than $1.5h_{ef}$. Drilling equipment and setting procedures shall be representative of normal anchor installation as specified by the anchor manufacturer.

10.2.2.2 Alternatively, tests in accordance with Section 9.9 and Section 9.10 shall be conducted with the test member supported with a shear span length (distance from anchor to support) not less than $1.5h_{ef}$. Drilling equipment and setting procedures shall be representative of normal anchor installation as specified by the manufacturer. Subsequent to drilling the holes and setting the anchors, the balance of tests in accordance with Section 9.9 and Section 9.10 shall be permitted to be conducted without supports.

11.0 ASSESSMENT

11.1 Normalization of anchor capacities for measured concrete bond and steel strengths for adhesive and torque-controlled adhesive anchors:

11.1.1 When reporting results and data and comparing anchor capacities of tests that require normalization to a specific or a common strength, the type of failure shall be taken into account.

11.1.2 Concrete breakout, splitting and pullout failure:

11.1.2.1 Normalize test results for the influence of the concrete compressive strength in accordance with Eq. 11.1.

$$F_{test,x,f_c} = F_{test,x} \cdot \left(\frac{f_c}{f_{c,test,x}} \right)^n \quad \text{lb (N)} \qquad \text{Eq. 11.1}$$

where:

F_{test,x,f_c} = test result normalized to considered concrete strength f_c, lb (N).

$F_{test,x}$ = test result from test series x, lb (N).

f_c = compressive strength corresponding to concrete to which the test result is to be normalized, psi (MPa).

$f_{c,test,x}$ = concrete compressive strength corresponding to concrete used for test series x, psi (MPa).

n = 0.5 for concrete breakout and splitting failure;

= shall be determined from tests when failure under tension load is characterized by pullout or when tests are performed as confined tests;

= 0.3 for bond force tests (see Section 8.22) in the absence of other substantiating data.

11.1.3 Anchor element failure:

11.1.3.1 Where failure is characterized by steel rupture, normalize the capacity for the nominal anchor element material strength using Eq. 11.2. For steels conforming to a standard, the characteristic tensile strength shall be taken as the minimum specified ultimate tensile strength f_{ut}.

$$F_{test,x,f_{ut}} = F_{test,x} \cdot \frac{f_{ut}}{f_{ut,test,x}} \quad \text{lb (N)} \qquad \text{Eq. 11.2}$$

where:

$F_{test,x,f_{ut}}$ = normalized test result, lb (N).

$F_{test,x}$ = test result from test series x, lb (N).

f_{ut} = steel tensile strength to which the test result is to be normalized, psi (MPa).

$f_{ut,test,x}$ = steel tensile strength corresponding to anchors used for test series x, psi (MPa).

11.2 Establishing characteristic values for adhesive and torque-controlled adhesive anchors:

11.2.1 The characteristic value shall be evaluated from the mean value and the associated coefficient of variation v using Eq. 11.3.

$$F_k = \overline{F}_{test,x} \cdot \left(1 - K \cdot v_{test,x}\right) \quad \text{lb (N)} \qquad \text{Eq. 11.3}$$

where:

K = tolerance factor corresponding to a 5% probability of non-exceedence with a confidence of 90%, derived from a noncentral t-distribution for which the population standard deviation is unknown. Values for specific samples sizes n are provided in Table 11.1.

F_k = characteristic value (5% fractile), lb (N).

$\overline{F}_{test,x}$ = mean of test results for test series x, lb (N).

$v_{test,x}$ = coefficient of variation of the population sample corresponding to test series x, %.

Table 11.1 – Tolerance factors for a 5% probability of non-exceedence with a confidence of 90%

Number of tests n	K	Number of tests n	K
3	5.311	21	2.190
4	3.957	22	2.174
5	3.400	23	2.159
6	3.092	24	2.145
7	2.894	25	2.132
8	2.754	26	2.120
9	2.650	27	2.109
10	2.568	28	2.099
11	2.503	29	2.089
12	2.448	30	2.080
13	2.402	35	2.041
14	2.363	40	2.010
15	2.329	45	1.986
16	2.299	50	1.965
17	2.272	60	1.933
18	2.249	120	1.841
19	2.227	240	1.780
20	2.208	∞	1.645

Source: Hahn, Gerald J. and Meeker, William Q., Statistical intervals: a guide for practitioners, John Wiley & Sons, Inc., 1991.

11.3 Assessment of characteristic tension capacity associated with concrete breakout and pullout for adhesive anchors:

11.3.1 Normalization for regional variations in concrete:

11.3.1.1 The primary laboratory shall determine the mean bond strength $\overline{\tau}_{ref,f_c}$ from the results of the combined round-robin tests in accordance with Eq. 11.4. If the mean bond strength corresponding to the tests conducted in any one laboratory is 15% greater than the mean of the combined results from the remaining three laboratories , that test series shall be discarded and the remaining three test series shall be used to establish $\overline{\tau}_{ref,f_c}$. This evaluation shall be performed separately for the results for unconfined and confined tests.

$$\overline{\tau}_{ref,f_c} = \frac{\overline{N}_{ref,f_c}}{\pi \cdot d \cdot h_{ef}} \quad \text{psi (MPa)} \qquad \text{Eq. 11.4}$$

where

$\bar{\tau}_{ref,f_c}$ = normalized mean bond strength corresponding to round-robin tests, psi (MPa).

$\bar{N}_{ref,f_c}$ = mean ultimate tension load for all round-robin tests normalized to concrete strength f'_c = 3,000 psi (20.7 MPa) in accordance with Section 11.1, lb (N).

11.3.1.2 Based on the results of the round-robin testing the calibration factor α_{conc} shall be evaluated in accordance with Eq. 11.5 separately for unconfined and confined round-robin tests. The minimum value of α_{conc} shall be used in Eq. 11.12. Where the primary laboratory uses data from more than one laboratory for the assessment of the service-condition tension capacity in low-strength concrete, a unique value of α_{conc} shall be calculated for each laboratory and applied to the service-condition tension test data originating from that laboratory.

$$\alpha_{conc} = \frac{\bar{\tau}_{ref,f_c}}{\bar{\tau}_{u,f_c}} \qquad \text{Eq. 11.5}$$

where:

$\bar{\tau}_{u,f_c}$ = for unconfined round-robin tests, the mean bond strength from service-condition tests in uncracked concrete normalized to concrete strength f'_c = 3,000 psi (20.7 MPa) in accordance with Section 11.1, psi (MPa).

or

$\bar{\tau}_{u,f_c}$ = for confined round-robin tests, the mean bond strength from reference tests in uncracked concrete tests normalized to concrete strength f'_c = 3,000 psi (20.7 MPa) in accordance with Section 11.1, psi (MPa)

11.3.2 Requirements on coefficient of variation:

11.3.2.1 In each reliability test series, the coefficient of variation $v_{test,x}$ of the ultimate loads shall not exceed 30%. For all other test series, the coefficient of variation $v_{test,x}$ of the ultimate loads shall not exceed 20%.

11.3.2.2 For cases where the coefficient of variation $v_{test,x}$ of the ultimate loads in reliability tests exceeds 20%, a reduction factor α_{cov} shall be determined in accordance with Eq. 11.6.

11.3.2.3 For cases where the coefficient of variation $v_{test,x}$ of the ultimate loads in tests other than reliability tests exceeds 15%, a reduction factor α_{cov} shall be determined in accordance with Eq. 11.6.

11.3.2.4 The minimum value of α_{cov} as determined in accordance with Section 11.3.2.2 and Section 11.3.2.3 shall control for the determination of τ_k in accordance with Eq. 11.12.

$$\alpha_{cov} = \frac{1}{1+0.03\left(v_{test,x} - COV\right)} \leq 1.0 \quad \text{Eq. 11.6}$$

where

$v_{test,x}$ = sample coefficient of variation for test series x equal to the mean divided by the sample standard deviation, %

COV = threshold coefficient of variation for adhesive anchors
= 20 for ultimate loads from reliability tests
= 15 for ultimate loads, tests other than reliability tests

11.3.3 Comparison with reference tests:

11.3.3.1 For those reliability and service-condition tests listed in Table 4.1 or Table 4.2 for which α_{req} is defined, calculate the value of α using Eq. 11.7 and the results of reference tension tests conducted in the same test member or concrete batch with anchors having the same diameter.

$$\alpha = min\left[\frac{\overline{\tau}_{u,i}}{\overline{\tau}_{o,i}};\frac{\tau_{k,i}}{\tau_{k,o,i}}\right] \quad \text{Eq. 11.7}$$

where

$\overline{\tau}_{u,i}$ = mean bond strength from reliability or service-condition test series in concrete batch or test member i, psi (MPa).

$\overline{\tau}_{o,i}$ = mean bond strength from reference test series in concrete batch or test member i, psi (MPa).

$\tau_{k,i}$ = characteristic bond strength from reliability or service-condition test series in concrete batch or test member i calculated in accordance with Section 0, psi (MPa).

$\tau_{k,o,i}$ = characteristic bond strength from reference test series in concrete batch or test member i calculated in accordance with Section 0, psi (MPa)

11.3.3.2 Comparison of the 5% fractile values shall be permitted to be omitted if either of the following conditions is met:

1. For both test series, the coefficient of variation of the failure loads $v \leq$ 10%.
2. The difference in the number of tests in the series to be compared is $\Delta n \leq 5$ and the coefficient of variation of the test series is equal to or less than the coefficient of variation of the reference test series.

11.3.4 Load-displacement behavior:

11.3.4.1 Uncontrolled slip under tension load corresponds to the loss of adhesion between the adhesive material and the concrete. Upon loss of adhesion, both the anchor rod and adhesive material are extracted together from the concrete. In such cases the subsequent load-slip behavior is substantially dependent on the roughness of the drilled hole. The onset of uncontrolled slip is therefore defined as loss of adhesion, and the load corresponding to loss of adhesion is denoted as N_{adh}.

11.3.4.2 The load N_{adh} shall be evaluated for each test of the reliability test series listed in Table 11.2, the service-condition test series listed in Table 11.3 as well as the installation safety tests in Table 11.4 or
11.3.4.3 Table **11.5**.

11.3.4.3.1 The load N_{adh} shall be evaluated by examination of the load-displacement curve recorded during the conduct of the test. In general, loss of adhesion is characterized by a significant change in stiffness as reflected in an abrupt change in the slope of load-displacement curve (See Fig. 11.1).

11.3.4.3.2 In cases where the load corresponding to loss of adhesion may not readily be identified by direct observation of the load-displacement curve, the load N_{adh} shall be evaluated as follows:

1. Compute the tangent to the load-displacement curve at a load $N = 0.3N_u$, where N_u is the peak tension load resisted by the anchor in the test. In general, the tangent stiffness k_{tan} can be conservatively estimated as the secant stiffness between the origin of the load-displacement curve and the point defined by $0.3N_u$ and $\Delta_{0.3}$ in accordance with Eq. 11.8.

$$k_{tan} \approx \frac{0.3N_u - N_{origin}}{\Delta_{0.3} - \Delta_{origin}} \qquad \text{Eq. 11.8}$$

   where:

   $\Delta_{0.3}$ = anchor displacement at $N = 0.3N_u$

2. Multiply the tangent stiffness by 2/3.
3. Project a straight line from the origin of the load-displacement curve with a slope corresponding to the stiffness as calculated in step 2.
4. The load N_{adh} shall be taken from the point of intersection between the projected line and the measured load-displacement curve (See Fig. 11.2).
5. If the peak load occurs at a displacement that is less than that corresponding to the intersection of the projected line and the load-displacement curve, then N_{adh} shall be taken as the peak load (See Fig. 11.3).
6. If the displacement $\Delta_{0.3} \leq$ 0.002 in. (0.05 mm), the origin of the projected line shall be shifted to a point on the load-displacement curve given by $0.3N_u$ and $\Delta_{0.3}$ (See Fig. 11.4).

11.3.4.4 For all values of N_{adh} calculated in accordance with Section 11.3.4.2, evaluate the adjustment factor α_{adh} using Eq. 11.9

$$\alpha_{adh} = \frac{N_{adh,i,j}}{0.5 \cdot N_{u,i,j}} \leq 1.0 \qquad \text{Eq. 11.9}$$

where

$N_{adh,i,j}$ = adhesion force corresponding to test series i, test j.

$N_{u,i,j}$ = ultimate load corresponding to test series i, test j.

11.3.4.5 In cases where a minimum of 10 replicates have been performed in a given test series, it shall be permitted to calculate α_{adh} for that test series in accordance with Eq. 11.10 in lieu of Eq. 11.9.

$$\alpha_{adh} = \frac{min\, N_{adh,i}}{0.5 \cdot \bar{N}_{u,i}} \leq 1.0 \qquad \text{Eq. 11.10}$$

where

$min\, N_{adh,i}$ = minimum value of adhesion force determined for test series i.

$\bar{N}_{u,i}$ = mean tension capacity for reliability test series i, lb (N).

11.3.4.6 Where failure under tension load is characterized by slip between the anchor rod and the adhesive material along the entire embedded length, evaluation of the load corresponding to loss of adhesion is not required and the value of α_{adh} shall be taken as 1.0

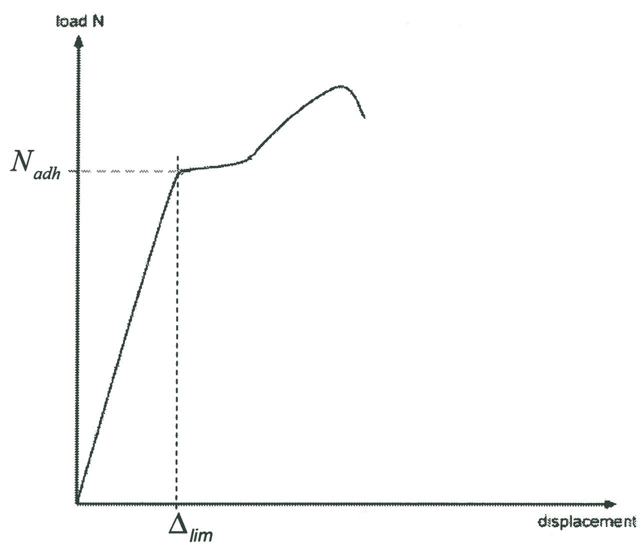


Fig. 11.1 – Evaluation of load at N_{adh}

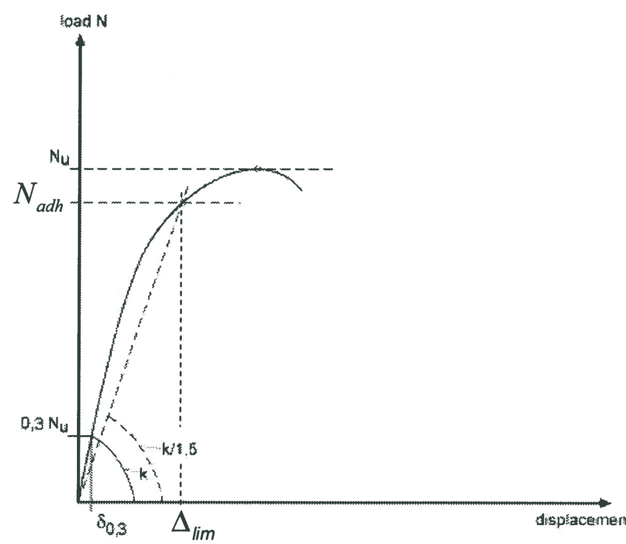


Fig. 11.2 – Evaluation of load at N_{adh}

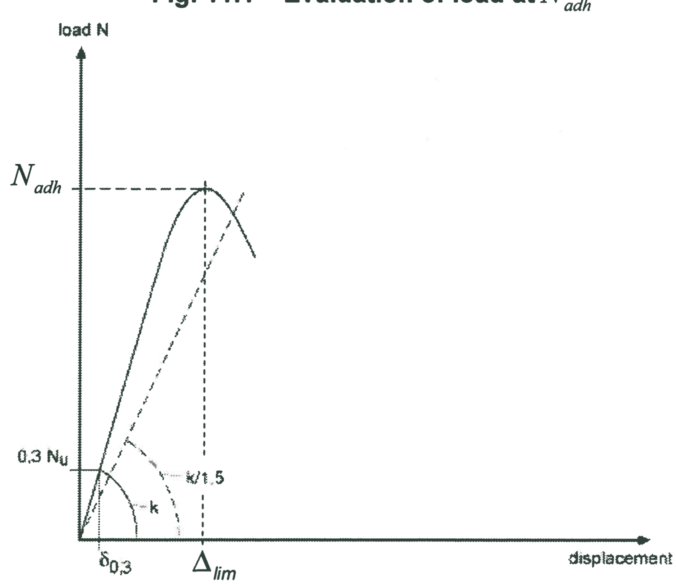


Fig. 11.3 – Evaluation of load at N_{adh}

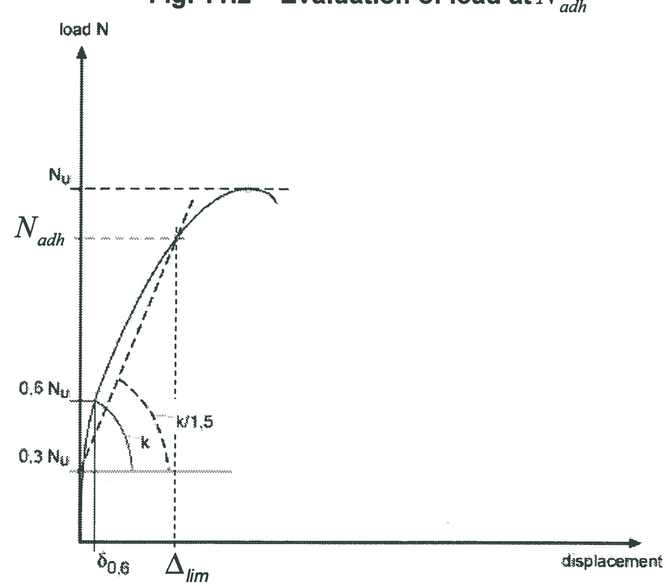


Fig. 11.4 – Evaluation of load at N_{adh}

11.3.5 Bond capacity:

11.3.5.1 For each service-condition tension test (Table 4.1, Test No. 7a and 7b, Table 4.2 Test Nos. 11a and 11b and Table 4.2 Test Nos. 11c and 11d), calculate the corresponding bond strength τ_i in concrete test member i or concrete batch i using Eq. 11.11.

$$\tau_i = \alpha_{setup} \cdot \frac{N_{u,i,f_c}}{\pi \cdot d \cdot h_{ef}} \quad \text{psi (MPa)} \qquad \text{Eq. 11.11}$$

where

N_{u,i,f_c} = peak tension load measured in a tension test conducted in test series i or concrete batch i, normalized to concrete strength f_c = 2,500 psi (17.2 MPa), lb (N).

α_{setup} = 1.0 if service condition tests are performed as unconfined tests.

= 0.75 if service condition tests in uncracked concrete are performed as confined tests.

= 0.70 if service condition tests in cracked concrete are performed as confined tests.

11.3.5.2 Nominal characteristic bond strength:

11.3.5.2.1 Calculate the nominal characteristic bond strength value $\tau_{k,nom(cr,uncr)}$ as applicable from the values τ_i in accordance with Section 0.

11.3.5.2.2 If the bond strength can be shown to vary with anchor diameter in a non-random manner, report the bond strength as a continuous function of tested anchor diameter. Otherwise, calculate a single bond strength $\tau_{k,nom(cr,uncr)}$ aggregating the results for all tested diameters.

11.3.5.3 Adjusted characteristic bond strength:

11.3.5.3.1 For adhesive anchors qualified in accordance with Table 4.1 and 4.2, reduce the nominal characteristic bond strength in uncracked concrete $\tau_{k,nom,uncr}$ in accordance with Eq. 11.12 and report the adjusted characteristic concrete bond resistance in uncracked concrete $\tau_{k,uncr}$ for each combination of mandatory and optional use conditions specified.

> Exception: For load cases with exclusively short-term loads such as wind or seismic, the factor α_ρ in accordance with Eq. 11.15 need not be included in the determination of τ_k in accordance with Eq. 11.12.

11.3.5.3.2 For adhesive anchors qualified in accordance with Table 4.2, reduce the nominal characteristic tension bond strengths in cracked and uncracked concrete $\tau_{k,nom(cr,uncr)}$ in accordance with Eq. 11.12 and report the adjusted characteristic concrete bond resistances in cracked concrete $\tau_{k,cr}$ and uncracked concrete $\tau_{k,uncr}$ for each combination of mandatory and optional use conditions specified.

Exception: For load cases with exclusively short-term loads such as wind or seismic, the factor α_ρ in accordance with Eq. 11.15 need not be included in the determination of τ_k in accordance with Eq. 11.12.

$$\tau_{k(cr,uncr)} = \tau_{k,nom(cr,uncr)} \cdot \beta \cdot \alpha_{lt} \cdot \alpha_{st} \cdot \alpha_{dur} \cdot \alpha_\rho \cdot \alpha_{conc} \cdot \alpha_{cov} \cdot \alpha_{cat\,3} \quad \text{psi (MPa)} \qquad \text{Eq. 11.12}$$

where:

β = $min\left[min\frac{\alpha}{\alpha_{req}}; min\,\alpha_{adh}\right]$ for the applicable reliability and service-condition tests listed in Table 11.2 and Table 11.3.

α = ratio of reliability test result to reference test result evaluated for all applicable reliability tests listed in Table 11.2, see Eq. 11.7.

α_{adh} = reduction factor for loss of adhesion as evaluated for all applicable reliability tests listed in Table 11.2 and for all service-condition tests listed in Table 11.3, see Section 11.3.4.2.

α_{req} = threshold value of α given in Table 4.1 or Table 4.2.

α_{lt} = reduction factor for maximum long-term temperature as applicable, see Eq. 11.33.

α_{st} = reduction factor for maximum short-term temperature as applicable, see Eq. 11.34.

α_{dur} = reduction factor for durability as applicable, see Eq. 11.36.

α_ρ = reduction factor for reduced sustained load in reliability tests as applicable, see Eq. 11.15.

α_{conc} = adjustment factor for regional concrete variation, see Section 11.3.1.

α_{cov} = reduction factor associated with the coefficient of variation of ultimate loads, see Eq. 11.6.

$\alpha_{cat\,3}$ = reduction factor for anchor category 3, see Eq. 11.14.

11.3.5.3.3 If the value $\tau_{k,cr}$ has been derived from service condition tests in cracked concrete performed as confined tests, the value $\tau_{k,cr}$ shall not exceed $\alpha_{conc} \cdot \tau_{k,nom,cr}$ where $\tau_{k,nom,cr}$ is evaluated from service condition tests in cracked concrete performed as unconfined tests and evaluated in accordance with Section 11.3.5.2.

11.3.5.4 Further modify the characteristic bond resistance $\tau_{k,cr}$ for seismic tension load cases in accordance with Eq. 11.13.

$$\tau_{k,seis} = \tau_{k,cr} \cdot \alpha_{N,seis} \quad \text{psi (MPa)} \qquad \text{Eq. 11.13}$$

where

$\alpha_{N,seis}$ = reduction factor for seismic tension loading, see Eq. 11.37.

$\tau_{k,seis}$ = seismic tension bond resistance, psi (MPa).

Table 11.2 – Reliability tests relevant for the determination of $min\frac{\alpha}{\alpha_{req}}$ and $min\,\alpha_{adh}$ in Eq. 11.12

Table 4.1			Table 4.2					
Test No.			Test No.					
3*	4	5*	3	4	5	6*	7	8*

* Optional tests

Table 11.3 – Service-condition tests relevant for the determination of $min\,\alpha_{adh}$ in Eq. 11.12

Table 4.1					Table 4.2							
Test No.					Test No.							
7a	7b	8a	8b*	8c	11a	11b	11c	11d	12a	12b*	12c	17*

* Optional tests

11.3.6 Anchor category:

11.3.6.1 The tested anchor system shall be assigned an anchor category in accordance with Table 11.4 or

11.3.6.2 Table **11.5**, depending on the installation conditions specified for the anchor and the results of the installation safety tests. The minimum value of α and α_{adh} for the tests listed in Table 11.4 or

11.3.6.3 Table **11.5** shall control the determination of the anchor category.

11.3.6.4 Where the controlling value of α or α_{adh} is less than the value of α_{req} corresponding to anchor category 3 in Table 11.4 or

11.3.6.5 Table **11.5**, the anchor shall be assigned to anchor category 3 and a reduction factor $\alpha_{cat\,3}$ for the determination of $\tau_{k(cr,uncr)}$ in accordance with Eq. 11.12 shall be determined in accordance with Eq. 11.14. For all other cases, $\alpha_{cat\,3}$ shall be taken as 1.0.

11.3.6.6 The anchor category shall be reported in Table 12.1 or Table 12.2.

Table 11.4 – Anchor categories for adhesive anchors subject to the installation conditions according to Table 11.10 (periodic inspection)

Anchor category	Value of α_{req} for selected installation safety tests				
	Installation safety test nos. according to Table 4.1 or Table 4.2				
	2a	2b*	2c*	2d*	2e
1	0.95	0.90	0.90	0.90	0.95
2	0.80	0.75	0.75	0.75	0.80
3	0.70	0.65	0.65	0.65	0.70

* Optional tests, refer to Table **11.10** for permissible combinations.

Table 11.5 – Anchor categories for adhesive anchors subject to the installation conditions according to Table 11.11 (continuous inspection and on-site proof loading program).

Anchor category	Value of α_{req} for selected installation safety tests							
	Installation safety test nos. according to Table 4.1 or Table 4.2							
	2a	2b*	2c*	2d*	2e	2f *†‡	2g*‡	2h*‡
1	0.80	0.75	0.75	0.75	0.80	0.90	0.90	0.90
2	0.70	0.65	0.65	0.65	0.70	0.75	0.75	0.75
3	0.60	0.55	0.55	0.55	0.60	0.65	0.65	0.65

* Optional tests, refer to Table 11.11 for permissible combinations.
† If Test 2g is performed, then Test 2f may be omitted.
‡ Omission of less severe tests is permitted in specific cases: e.g., if the desired category is fulfilled with the results of Tests 2b, 2c, and 2d, then Tests 2f, 2g and 2h may be omitted.

$$\alpha_{cat\,3} = min\left[min\frac{\alpha}{\alpha_{req,cat\,3}}; min\frac{\alpha_{adh}}{\alpha_{req,cat\,3}} \right] \leq 1.0 \qquad \text{Eq. 11.14}$$

where

$\alpha_{req,cat\,3}$ = α_{req} corresponding to anchor category 3 for corresponding installation safety test in accordance with Table 11.4 or

Table **11.5**.

11.3.7 Adjustment for reduced sustained load:

11.3.7.1 Where a reduced sustained load is required to meet the displacement requirements in a reliability test series, the reduction factor α_ρ shall be evaluated in accordance with Eq. 11.15.

$$\alpha_\rho = min\left[\frac{N_{red}}{N_{req}}\right] \leq 1.0 \qquad \text{Eq. 11.15}$$

where:

N_{red} = reduced sustained load in a reliability test series as required to satisfy displacement criteria, lb [N]; and

N_{req} = required sustained load for a reliability test series, lb [N];

= N_w for tests in accordance with Eq. 8.1;

= $N_{sust,ft}$ for tests in accordance with Eq. 8.2;

= $N_{sust,lt}$ for tests in accordance with Eq. 8.3.

11.3.8 Concrete cone breakout capacity: It shall be permitted to evaluate the effectiveness factor k_{cr} and k_{uncr} for adhesive anchors in accordance with 11.4.7. Unconfined tension tests shall be conducted at the smallest, middle and largest diameters in low and high strength concrete with five (5) replicates per test series. The tests shall be conducted at the greatest embedment depth for which concrete cone failure is anticipated to occur. This embedment may be approximated using Eq. 11.16. The assessment of the effectiveness factor shall fulfill the conditions given in Section 11.4.7.2 in accordance with Table 11.6 for all test series.

$$h_{ef} = \frac{\left[\frac{\tau_{u,fc,uncr} \cdot \pi \cdot d_o}{k_{m,uncr}}\right]^2}{f_c'} \qquad \text{Eq. 11.16}$$

where

$\tau_{u,f_c,uncr}$ = the mean bond strength evaluated from unconfined tests in uncracked concrete normalized to f'_c;

and

$k_{m,uncr}$ = 40 for recognition of k_{uncr} = 30

= 35 for recognition of k_{uncr} = 27.

11.4 Assessment of characteristic tension capacity associated with concrete breakout and pullout for torque-controlled adhesive anchors:

11.4.1 Verification of test requirement: The testing and assessment of torque-controlled adhesive anchors shall be conducted in accordance with Table 4.4.

11.4.1.1 Exception: If tests to determine the slip force and bond force have been conducted in accordance with Table 4.3, Test Nos. 10a and 10b, respectively, and it can be shown that either Eq. 11.17 or Eq. 11.18 is fulfilled, then testing and assessment of torque-controlled adhesive anchors shall be permitted to be conducted in accordance with Table 4.3.

11.4.2 Slip force and bond force test assessment:

11.4.2.1 In the slip force and bond force tests, the load at which loss of adhesion between the adhesive and the concrete occurs shall be determined in accordance with Section 11.3.4.

11.4.2.2 The results of the bond force tests shall be normalized to f_c = 2,500 psi (17.2 MPa) in accordance with Section 11.1. The coefficient of variation of the slip force tests shall not exceed 15% and the coefficient of variation of the bond force tests shall not exceed 10%. If these conditions are not fulfilled, a larger ratio of bond force to slip force shall be required in Eq. 11.17 or Eq. 11.18 to ensure that the slip force exceeds the bond force with a probability $p = 10^{-3}$.

$$\frac{\bar{N}_{bond,\phi}}{\bar{N}_{slip,\phi}} > 3.0 \qquad \text{Eq. 11.17}$$

where:

$\bar{N}_{bond,\phi}$ = the mean force corresponding to loss of adhesion between the adhesive and the concrete (mean bond force) for anchor diameter ϕ, lb [N]; and

$\bar{N}_{slip,\phi}$ = the mean force corresponding to loss of adhesion between the anchor element and the adhesive (mean slip force) for anchor diameter ϕ, lb [N].

$$\frac{N_{k,bond,\phi}}{N_{95\%,slip,\phi}} > 1.3 \qquad \text{Eq. 11.18}$$

where:

$N_{k,bond,\phi}$ = the characteristic force (5% fractile, 90% confidence) corresponding to loss of adhesion between the adhesive and the concrete (characteristic bond force) for anchor diameter ϕ, lb [N]; and

$N_{95\%,slip,\phi}$ = the 95% fractile at 90% confidence of the force corresponding to loss of adhesion between the anchor element and the adhesive (characteristic slip force) for anchor diameter ϕ, lb [N].

11.4.3 Torque-controlled adhesive anchors shall not exhibit pull-out characterized by failure at the adhesive/concrete boundary. Pull-out failure whereby the failure occurs at the adhesive/anchor element boundary is permissible.

11.4.4 Requirements on coefficient of variation:

11.4.4.1 In each reliability test series, the coefficient of variation $v_{test,x}$ of the ultimate loads shall not exceed 20%.

For all other test series, the coefficient of variation $v_{test,x}$ of the ultimate loads shall not exceed 15%.

11.4.5 Comparison with reference tests:

11.4.5.1 For all reliability tests listed in Table 4.3 or Table 4.4 with the exception of torque tests, slip force tests and bond force tests, calculate the value α using Eq. 11.19.

$$\alpha = min\left[\frac{\bar{N}_{r,i}}{\bar{N}_{o,i}};\frac{N_{k,r,i}}{N_{k,o,i}}\right] \leq 1.0 \qquad \text{Eq. 11.19}$$

where:

$\bar{N}_{r,i}$ = mean failure load from reliability test series i, lb (N).

$\bar{N}_{o,i}$ = mean failure load from the corresponding reference test series, lb (N).

$N_{k,r,i}$ = characteristic failure load from reliability test series i calculated in accordance with Section 0, lb (N).

$N_{k,o,i}$ = characteristic failure load from the corresponding reference test series calculated in accordance with Section 0, lb (N).

11.4.5.2 The evaluation of $\frac{N_{k,r,i}}{N_{k,o,i}}$ in Eq. 11.19 is valid for cases where a comparable number of test results are used for both series (reliability and reference). Comparison of the characteristic values may be omitted if either of the following conditions is met:

1. For both test series, the coefficient of variation of the failure loads $v \leq$ 10%.
2. The difference in the number of tests in each series $\Delta n \leq 5$ and the coefficient of variation of the reliability test series is equal to or less than the coefficient of variation of the reference test series.

11.4.5.3 For the purpose of evaluating α in accordance with Eq. 11.19, the value $N_{k,o,i}$ shall be permitted to be calculated using Eq. 11.20. In this case, $\bar{N}_{o,i}$ shall be taken as $1.3N_{k,o,i}$.

$$N_{k,o,i} = kh_{ef}^{\ 1.5}\sqrt{f_{c,i}} \ \text{lb [N]} \qquad \text{Eq. 11.20}$$

where

$k\left(k_{cr},k_{uncr}\right)$ = calculated according to Section 11.4.7

11.4.6 Requirements for load-displacement behavior:

11.4.6.1 The tension load-displacement behavior of single torque-controlled adhesive anchors shall be predictable, except as noted in Sections 11.4.6.1.1 and 11.4.6.1.2. Fig. 11.5 provides examples of acceptable and unacceptable load-displacement curves for torque-controlled adhesive anchors. For each anchor tested, a plateau with a slip larger than 5% of the displacement at ultimate load, or a temporary drop in load, shall not occur at load levels less than N_1. For tests in uncracked concrete, N_1 is taken as the lesser of $0.8N_u$ and $A_{se}f_y$. For tests in cracked concrete, N_1 is taken as the lesser of $0.7N_u$ and $A_{se}f_y$. This requirement shall be fulfilled in all confined and unconfined tension tests specified in Table 4.3 and Table 4.4 that are conducted to failure with continuous measurement of load and displacement.

11.4.6.1.1 Exception: Minor deviations in the tension load-displacement behavior from the requirements of Section 11.4.6.1 at the point of loss of adhesion between the anchor element and the adhesive shall be permitted when conducting tests in cracked concrete. Such deviations, characterized by a loss of load prior to the attainment of peak load, shall not extend for more than 0.020 inches (0.5 mm) of displacement.

11.4.6.1.2 Exception: Within a test series, if not more than one test shows a load-displacement curve not complying with Section 11.4.6.1, the anchor shall be considered acceptable provided that two conditions are met:

1. There is little or no drop in load; and
2. The deviation is justified as being uncharacteristic of the anchor behavior and is due to an external cause such as a defect in the test procedure or in the base material. Such defects shall be described in detail in the evaluation report, and the results of an additional ten tension tests shall display load-displacement curves meeting the requirements of Section 11.4.6.1.

11.4.6.2 Where the requirements of Section 11.4.6.1 are not met in reliability and service-condition tension tests, calculate the adjustment factor α_{slip} in accordance with Eq. 11.21.

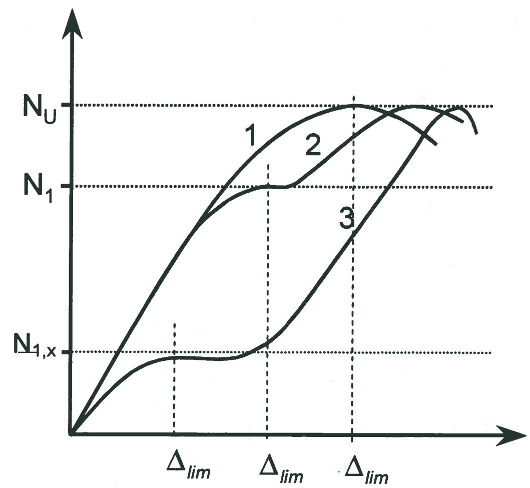
$$\alpha_{slip} = \frac{N_{1,x}}{N_1} \leq 1.0 \qquad \text{Eq. 11.21}$$

where:

N_1 = $min\left[0.8N_u; A_{se}f_y\right]$ uncracked concrete, lb (N).

= $min\left[0.7N_u; A_{se}f_y\right]$ cracked concrete, lb (N).

$N_{1,x}$ = load corresponding to uncontrolled slip in tension test x, lb (N).



Curves 1 and 2 show load-displacement responses in conformance with Section 11.4.6.1.
Curve 3 shows uncontrolled slip requiring calculation of α_{slip} . See Section 11.12.3 for requirements on Δ_{lim} .

Fig. 11.5 – Load-displacement requirements

11.4.7 Concrete cone breakout capacity:

11.4.7.1 Evaluate the concrete cone breakout capacity N_m from test results considering test conditions and sample size.

11.4.7.2 Calculate mean effectiveness factors k_m independently for unconfined tension tests conducted in uncracked concrete and for unconfined tension tests conducted in cracked concrete using Eq. 11.22.

$$k_m = \frac{\overline{N}_u}{\beta_1 \cdot h_{ef}^{1.5} \sqrt{f_{c,test,i}}} \quad \text{in., lb [N, mm)} \qquad \text{Eq. 11.22}$$

where:

$$\beta_1 = 1 - \frac{0.19}{\sqrt{n}}$$

$n =$ no. of tests included in evaluation of $\overline{N}_u$

11.4.7.3 If the values of k_m calculated with Eq. 11.22 do not meet the minimum permissible values of k_m given in Table 11.6, the minimum value of k in Table 11.6 shall be reported and the characteristic tension resistance shall be determined in accordance with Section 11.4.8.1. The values of k_{uncr} and k_{cr} reported in Table 12.3 shall not exceed the maximum reportable k values given in Table 11.6.

Table 11.6 – Minimum and maximum values of effectiveness factors, k_{cr} and k_{uncr}

Effectiveness factor	Permissible range of calculated mean effectiveness factor, k_m		Value of k_{cr} and k_{uncr} to be reported	
	in., lb	SI	in., lb	SI
k_{cr}	$22 \le k_m < 27$	$9.2 \le k_m < 11.3$	17	7.1
	$27 \le k_m < 32$	$11.3 \le k_m < 13.4$	21	8.8
	$k_m \ge 32$	$k_m \ge 13.4$	24	10.0
k_{uncr}	$32 \le k_m < 35$	$13.4 \le k_m < 14.6$	24	10.0
	$35 \le k_m < 40$	$14.6 \le k_m < 16.7$	27	11.3
	$k_m \ge 40$	$k_m \ge 16.7$	30	12.6

11.4.7.4 If tension tests conducted at the embedment and steel strength reported in Table 12.3 result in steel failure at a load corresponding to a k that is less than the minimum reportable value from Table 11.6, report the minimum reportable values given in Table 11.6 for k_{cr} and k_{uncr}. If tension tests conducted at the embedment and steel strength reported in Table 12.3 result in steel failure at a load corresponding to a k that is greater than the minimum reportable value from Table 11.6, report the corresponding values k_{cr} and k_{uncr} from Table 11.6. Alternatively, it shall be permitted to perform the tests used to determine the effectiveness factors in such a manner as to result in concrete failure. Acceptable methods include substituting a bolt of higher steel strength in the anchor or setting the anchor at a reduced embedment depth. Where a change in the specified components of the anchor is required, an assessment shall be made to determine that the functioning of the anchor is not enhanced by the required modification.

11.4.8 Pull-out capacity:

11.4.8.1 For torque-controlled adhesive anchors qualified in accordance with Table 4.3 or Table 4.4, reduce the nominal characteristic tension pullout capacities for cracked and uncracked concrete $N_{k,p,nom(cr,uncr)}$ in accordance with Eq. 11.23 and report the characteristic pull-out capacity in cracked and uncracked concrete $N_{k,p(cr,uncr)}$ for each combination of mandatory and optional use conditions specified.

Exception: For short-term loads such as wind or earthquake, the factor α_p in accordance with Eq. 11.15 need not be included in the determination of $N_{k,p}$ in accordance with Eq. 11.23.

$$N_{k,p(cr,uncr)} = N_{k,p,nom(cr,uncr)} \cdot \beta \cdot \alpha_{lt} \cdot \alpha_{st} \cdot \alpha_{dur} \cdot \alpha_{\rho} \cdot \alpha_{cat3} \quad \text{lb [N]} \qquad \text{Eq. 11.23}$$

where:

$N_{k,p,nom,uncr}$ = the characteristic capacity as determined from service-condition tests in low- and high-strength uncracked concrete in accordance with this criteria.

$N_{k,p,nom,cr}$ = the characteristic capacity as determined from service-condition tests in low- and high-strength cracked concrete in accordance with this criteria.

β = $min\left[min\frac{\alpha}{\alpha_{req}}; min\,\alpha_{slip}\right]$ for the reliability and service-condition tests listed in Table 11.7 and Table 11.8, respectively.

α_{slip} = reduction factor for uncontrolled slip, see Eq. 11.21.

α_{lt} = reduction factor for maximum long-term temperature, see Eq. 11.33.

α_{st} = reduction factor for maximum short-term temperature, see Eq. 11.34.

α_{dur} = reduction factor for durability, see Eq. 11.36.

α_{p} = min. reduction factor for reduced sustained/repeated load in reliability tests, see Eq. 11.26.

α_{cat3} = reduction factor for anchor category 3, see Eq. 11.25.

Table 11.7 – Reliability tests relevant for the determination of $min\frac{\alpha}{\alpha_{req}}$ and $min\,\alpha_{slip}$ in Eq. 11.23.

Table 4.3						Table 4.4					
Test No.						Test No.					
3	4	5	6*	7	8*	3	4	5	6*	7	8*

*Optional tests.

Table 11.8 – Service-condition tests relevant for the determination of $min\,\alpha_{slip}$ in Eq. 11.23.

Table 4.3								Table 4.4							
Test No.								Test No.							
11a	11b	11c	11d	12a	12b*	12c	17*	10a	10b	10c	10d	11a	11b*	11c	16*

*Optional tests.

11.4.8.2 Further modify the characteristic tension resistance $N_{k,p,cr}$ for seismic load cases in accordance with Eq. 11.24

$$N_{k,p,seis} = N_{k,p,cr} \cdot \alpha_{N,seis} \quad \text{lb [N]} \qquad \text{Eq. 11.24}$$

where:

$\alpha_{N,seis}$ = reduction factor for seismic tension loading, see Eq. 11.37.

$N_{k,p,seis}$ = seismic tension pull-out resistance, lb (N).

11.4.9 Anchor category:

11.4.9.1 The tested anchor system shall be assigned an anchor category in accordance with Table 11.9. The anchor category shall be reported in Table 12.3.

Table 11.9 – Anchor categories for torque-controlled adhesive anchors

Anchor category	Value of α_{req} for selected installation safety tests											
	Table 4.3						Table 4.4					
	Test No.						Test No.					
	2a	2b	2c*	2d*	2e*	2f	2a	2b	2c*	2d*	2e*	2f
1	0.95	0.95	0.90	0.90	0.90	0.90	0.95	0.95	0.90	0.90	0.90	0.90
2	0.80	0.80	0.75	0.75	0.75	0.75	0.80	0.80	0.75	0.75	0.75	0.75
3	0.70	0.70	0.65	0.65	0.65	0.65	0.70	0.70	0.65	0.65	0.65	0.65

*Optional tests, see Table 11.12.

11.4.9.2 Where α is less than the values of α_{req} corresponding to anchor category 3 in Table 11.9, the anchor shall be assigned to anchor category 3 and a reduction factor α_{cat3} for the determination of $N_{k,p(cr,uncr)}$ in accordance with Eq. 11.23 shall be determined in accordance with Eq. 11.25. For all other cases, α_{cat3} shall be taken as 1.0.

$$\alpha_{cat3} = \min\left[\frac{\alpha}{\alpha_{req.cat3}}\right] \leq 1.0 \qquad \text{Eq. 11.25}$$

where

$\alpha_{req,cat3}$ = α_{req} corresponding to anchor category 3 for corresponding installation safety test in accordance with Table 11.9.

11.4.10 Adjustment for reduced sustained load:

11.4.10.1 Where a reduced sustained load is required to meet the displacement requirements in a reliability test series, the reduction factor α_ρ shall be evaluated in accordance with Eq. 11.26.

$$\alpha_\rho = min\left[\frac{N_{red}}{N_{req}}\right] \leq 1.0 \qquad \text{Eq. 11.26}$$

where:

N_{red} = reduced sustained or repeated load in a reliability test series as required to satisfy displacement criteria; and

N_{req} = required sustained or repeated load for a reliability test series;

= N_w for tests in accordance with Eq. 8.1;

= $N_{sust,ft}$ for tests in accordance with Eq. 8.2;

= $N_{sust,lt}$ for tests in accordance with Eq. 8.3.

11.5 Assessment of steel tension capacity for adhesive and torque-controlled adhesive anchors:

11.5.1 The steel tension capacity shall be evaluated in accordance with Section D.5.1.2 of ACI 318 Appendix D.

11.5.2 Where the steel anchor element carrying tension load has a variable cross section, A_{se} shall be taken as the minimum cross sectional area over the load-bearing length of the anchor.

11.6 Assessment of steel shear capacity for adhesive and torque-controlled adhesive anchors:

11.6.1 For anchors without a reduced cross section within five diameters of the shear plane, the steel shear capacity shall be evaluated in accordance with Eq. (D-19) in Section D.6.1.2 of ACI 318 Appendix D.

11.6.2 For anchors without threads in the critical shear plane, A_{se} shall be taken as the gross anchor cross sectional area.

11.6.3 For anchors with threads in the shear plane but without a reduced section, A_{se} shall be taken as 75 percent of the gross anchor cross sectional area.

11.6.4 For anchors with a reduced section within five diameters of the shear plane, V_s shall be determined by test as prescribed in Section 9.11 but shall not exceed the value determined in accordance with Section D.6.1.2 of ACI 318 Appendix D assuming an unreduced cross-section.

11.6.5 Further modify the shear capacity V_s for seismic load cases in accordance with Eq.

$$V_{s,seis} = V_s \cdot \alpha_{V,seis} \quad \text{lb [N]} \qquad \text{Eq. 11.27}$$

where

$\alpha_{V,seis}$ = reduction factor for seismic shear loading, see Eq. 11.38.

V_s = steel shear capacity determined in accordance with Sections 11.6.1, 11.6.2, 11.6.3 and 11.6.4.

$V_{s,seis}$ = seismic shear capacity of the anchor as governed by steel failure.

11.6.5.1 For anchor diameters not tested in shear, the minimum value of $\alpha_{V,seis}$ determined for the neighboring anchor diameters shall be used in Eq. 11.27.

11.7 Assessment of minimum member thickness for adhesive anchors:

11.7.1 In those test series where the minimum member thickness h_{min} is required to be used, the tests shall be conducted in members having the minimum member thicknesses specified for each anchor type, diameter, and embedment. The minimum member thickness h_{min} shall not be less than the value given by Eq. 11.28.

$$h_{min} = h_{ef} + \Delta h \geq 2.00 \text{ in. (50 mm)} \qquad \text{Eq. 11.28}$$

where:

$\Delta h \geq 2d_o \geq$ 1.25 in. (30 mm) Applies to all anchor types without restriction.

$\Delta h \geq d_o \geq$ 0.60 in. (15 mm) Applies to all anchor types in cases where the remote face of the concrete member can be inspected. If concrete breakthrough occurs during drilling, measures shall be taken to ensure that the effective anchor embedment has not been compromised and that adhesive material losses are compensated.

$\Delta h = 0$ Applies to injection anchor systems in cases where the effective anchor embedment is adjusted for spalling on the backside of the concrete member and measures are taken to ensure that adhesive material losses are compensated

11.8 Assessment of minimum member thickness for torque-controlled adhesive anchors

11.8.1 Unless separate tests are conducted in accordance with Section 10.2 to verify minimum member thicknesses for specific types, diameters and embedments, the minimum member thickness h_{min} shall be reported as $h_{min} = 2h_{ef}$.

11.8.1.1 In no case shall the minimum member thickness be given as less than the drilled hole depth $+\Delta h$ whereby $\Delta h = d_o \geq$ 1.25 in. (30 mm).

11.9 Assessment of maximum installation torque for adhesive and torque-controlled adhesive anchors:

11.9.1 The torque resistance in the torque tests (see Section 8.20) shall achieve a torque resistance of at least $1.3T_{inst}$ in all tests. The anchor shall not turn in the anchor hole prior to reaching a torque resistance of $1.3T_{inst}$. In addition, Eq. 11.29 shall be fulfilled. If this requirement is not met, the installation torque T_{inst} shall be reduced as required to fulfill Eq. 11.29.

$$N_{95\%} \leq min\,[F_y;\ 0.8 \cdot N_{k,test}] \quad \text{lb [N]} \qquad \text{Eq. 11.29}$$

where:

$N_{95\%}$ = 95% fractile (90% confidence) of the induced tension force corresponding to $1.3T_{inst}$.

$N_{k,test}$ = characteristic tension capacity evaluated from reference tension tests in low strength concrete as follows: Table 4.1, Test No. 1a; Table 4.2, Test No. 1a; Table 4.3, Test No. 1a; Table 4.4, Test No. 1a.

F_y = $A_{se} \cdot f_y$ for bolts with a defined yield stress.

= $A_{se} \cdot 0.8 f_u$ for bolts without a well-defined yield stress.

11.9.2 It shall be permitted to satisfy Eq. 11.29 for adhesive anchors by calculation. For this purpose Eq. 11.30 may be used.

$$N_{95\%} = \frac{1.3T_{inst}}{k \times d} \qquad \text{Eq. 11.30}$$

with

k = friction factor. The friction factor shall be taken as a lower bound value. For normal threaded rods without lubricants or friction-reducing coatings, $k = 0.2$ may be assumed.

11.10 Assessment of behavior under crack cycling for adhesive and torque-controlled adhesive anchors:

11.10.1 In each test in cracks whose opening width is cycled, the cumulative recorded anchor displacement shall not exceed 0.080 in. (2.0 mm) following the initial 20 cycles of crack opening and closing, nor 0.120 in. (3.0 mm) following 1,000 cycles.

11.10.2 If the anchor displacement exceeds these limits during the crack-cycling portion of the test, it shall be permitted to increase the number of replicates. For a sample size of 10 to 20 replicates, one of the tested anchors shall be permitted to exhibit a maximum displacement of 0.120 in. (3.0 mm) after the initial 20 cycles and 0.160 in. (4.0 mm) after 1000 cycles. For sample sizes larger than 20, 5% of the tested anchors shall be permitted to exhibit these increased displacements. If the requirements are not met, repeat the tests with a reduced sustained load until the requirements are met and evaluate the reduction factor α_ρ in accordance with Section 11.3.7 or Section 11.4.10.1.

11.10.3 The value of α_{req} for the residual tension capacity is 0.90.

11.11 Assessment of freeze/thaw behavior for adhesive and torque-controlled adhesive anchors:

11.11.1 The rate of displacement increase in the freeze/thaw tests (see Section 8.17) shall decline with increasing number of freeze/thaw cycles, approaching zero.

11.11.2 If the requirement on displacement is not met, reduce the sustained load until the requirement is met and evaluate the reduction factor α_ρ in accordance with Section 11.3.7 or Section 11.4.10.1.

11.11.3 The value of α_{req} for the residual tension capacity shall be 0.90.

11.12 Assessment of sustained load behavior for adhesive and torque-controlled adhesive anchors:

11.12.1 The total displacement over the anchor intended service life, which includes the initial elastic displacement plus the creep displacement, is determined for each specimen by projecting a logarithmic trend line forward over the intended anchor service life. The trend line shall be determined by calculating a least squares fit through the data points using Eq. 11.31 and shall be constructed with data from not less than the last 20 days (minimum of 20 data points) of the creep test.

$$\Delta(t) = \Delta_{t=0} + a \cdot t^b \qquad \text{Eq. 11.31}$$

where:

$\Delta(t)$ = total displacement recorded in the test at time t

$\Delta_{t=0}$ = initial displacement recorded under sustained load;

t = the time corresponding to the total recorded displacement (hours)

a , b = constants evaluated by regression analysis

11.12.2 Calculate the estimated displacement corresponding to the anchor intended service life for each test using Eq. 11.32.

$$\Delta_{service} = \Delta_{t=0} + a \cdot \left(t_{service}\right)^{b}$$ Eq. 11.32

where:

$\Delta_{service}$ = extrapolated estimate of the total displacement over the anchor intended service life;

$\Delta_{t=0}$ = initial displacement recorded under sustained load;

$t_{service}$ = the intended anchor service life (hours);

= 50 years (standard temperature conditions)

= 10 years (elevated temperature conditions)

a, b = constants evaluated by regression analysis in accordance with Section 11.12.1.

11.12.3 The mean values of the extrapolated estimates of the total displacement over the anchor intended service life $\overline{\Delta}_{service}$ at standard temperature and at the long-term elevated temperature shall not exceed Δ_{lim} where Δ_{lim} is the mean displacement corresponding to loss of adhesion N_{adh} for adhesive anchors (see Section 11.3.4 and Fig. 11.1 through Fig. 11.4) or to uncontrolled slip $N_{1,x}$ for torque-controlled adhesive anchors (see Section 11.4.6 and Fig. 11.5) as measured in the corresponding reference tests at standard temperature and maximum long-term elevated temperature, respectively.

11.12.4 Reported anchor displacement shall be corrected to reflect the anchor displacement at the concrete surface.

11.12.5 The calculated estimated displacement $\Delta_{service}$ for any one test shall not exceed 1.2 Δ_{lim} with Δ_{lim} as defined in Section 11.12.3.

11.12.6 If the requirements on displacement are not met, repeat the sustained load tests with a reduced sustained load until the requirements are met and evaluate the reduction factor α_{ρ} in accordance with Section 11.3.7 or Section 11.4.10.1.

11.12.7 The value of α_{req} for the residual tension capacity shall be 0.90.

11.13 Assessment of performance associated with installation direction for adhesive and torque-controlled adhesive anchors:

11.13.1 When installed horizontally and overhead in accordance with the manufacturer's printed installation directions, the annular gap around the anchor element shall remain completely filled with adhesive and the anchor element shall not move perceptibly during the cure time (See Section 11.16).

11.13.2 The value of α_{req} for the tension capacity shall be 0.90.

11.14 Assessment of performance at elevated temperature for adhesive and torque-controlled adhesive anchors:

11.14.1 From the tension test results at the long-term test temperature, calculate α_{lt} using Eq. 11.33.

$$\alpha_{lt} = min\left[\frac{\bar{N}_{lt}}{\bar{N}_o};\frac{N_{k,lt}}{N_{k,o}}\right] \leq 1.0 \qquad \text{Eq. 11.33}$$

11.14.2 From the tension test results at the short-term test temperature, calculate α_{st} using Eq. 11.34.

$$\alpha_{st} = min\left[\frac{\bar{N}_{st}}{0.8\bar{N}_{lt}};\frac{N_{k,st}}{0.8N_{k,lt}}\right] \leq 1.0 \qquad \text{Eq. 11.34}$$

11.14.3 Comparison of the 5% fractile values shall be omitted if either of the following conditions is met:

3. For both test series, the coefficient of variation of the failure loads is $v \leq 10\%$.
4. The difference in the number of tests in each series is $\Delta n \leq 5$ and the coefficient of variation of the temperature test series is equal to or less than the coefficient of variation of the reference test series.

11.14.4 See Section 11.12 for requirements on displacement.

11.15 Assessment of performance with decreased installation temperature for adhesive and torque-controlled adhesive anchors:

11.15.1 For anchors recommended for installation in concrete temperatures below 50°F (10°C), the mean and the 5% fractile of the failure loads associated with the reduced temperature installation shall equal or exceed (or be shown to be statistically equivalent to) the mean and the 5% fractile of the corresponding reference tests.

11.15.1.1 Comparison of the 5% fractile values may be omitted if either of the following conditions is met:

1. For both test series, the coefficient of variation of the failure loads is $v \leq 10\%$.
2. The difference in the number of tests in each series is $\Delta n \leq 5$ and the coefficient of variation of the temperature test series is equal to or less than the coefficient of variation of the reference test series.

11.15.2 For anchors recommended for installation in concrete temperatures below 40°F (5°C), the conditions of Section 11.15.1 shall be fulfilled. In addition, the displacement of the anchor under sustained load just prior to tension testing to failure shall stabilize to the degree that an assessment can be made that failure is unlikely to occur.

11.15.3 Anchors that do not fulfill the requirements for a given target temperature shall be retested at a temperature at which the requirements are fulfilled. The temperature at which the requirements are fulfilled shall be reported as the minimum concrete temperature at the time of installation.

11.16 Assessment for cure time at standard temperature:

11.16.1 The results of the tests for curing at standard temperature shall be assessed in accordance with Eq. 11-35.

$$min\left[\frac{\bar{N}_{cure}}{\bar{N}_{cure+24h}};\frac{N_{k,cure}}{N_{k,cure+24h}}\right] \geq 0.9 \qquad \text{Eq. 11.35}$$

where

$\bar{N}_{cure}$ = mean tension capacity corresponding to the manufacturer's published minimum cure time, lb (N);

$\bar{N}_{cure+24h}$ = mean tension capacity corresponding to the manufacturer's published minimum cure time plus 24 hours, lb (N);

$N_{k,cure}$ = characteristic tension capacity corresponding to the manufacturer's published minimum cure time, lb (N);

$N_{k,cure+24h}$ = characteristic tension capacity corresponding to the manufacturer's published minimum cure time plus 24 hours, lb (N).

11.16.2 Comparison of the 5% fractile values shall be omitted if either of the following conditions is met:

1. For both test series, the coefficient of variation of the failure loads is $v \leq 10\%$.
2. The difference in the number of tests in each series is $\Delta n \leq 5$ and the coefficient of variation of the temperature test series is equal to or less than the coefficient of variation of the reference test series.

11.16.3 If the condition of Eq. 11.35 is not fulfilled, the cure time should be increased and the test shall be repeated until Eq. 11.35 is fulfilled.

11.16.4 The cure time at standard temperature as used in the cure time tests shall be reported.

11.17 Assessment of durability requirement for adhesive and torque-controlled adhesive anchors:

11.17.1 Requirement: From the punch tests, calculate the reduction factor α_{dur} using Eq. 11.36:

$$\alpha_{dur} = \frac{min\,\bar{\tau}_{dur,i}}{0.95\,\bar{\tau}_{o,i}} \leq 1.0 \qquad \text{Eq. 11.36}$$

where

$\bar{\tau}_{dur,i}$ = mean bond strength corresponding to durability tests with test member i or concrete batch i stored in different media calculated according to Eq. 9.1.

$\bar{\tau}_{o,i}$ = mean reference bond strength corresponding to durability tests with test member i or concrete batch i.

11.17.1.1 Exception: For the assessment of torque-controlled adhesive anchors in cracked concrete where all-thread rod has been substituted for the anchor element specified by the manufacturer, the value of α_{dur} in Eq. 11.12 shall be taken as 1.0 if $\frac{min\,\bar{\tau}_{dur,i}}{0.95\,\bar{\tau}_{o,i}} \geq 0.9$.

11.18 Assessment of performance in corner test for adhesive and torque-controlled adhesive anchors:

11.18.1 The tension capacity of the anchor positioned in the corner of a test member with edge distances c_{cr} and minimum member thickness h_{min} shall be statistically equivalent to the tension capacity from reference tests performed away from edges. Report the critical edge distance, c_{cr}, and the corresponding minimum member thickness in Table 12.1, Table 12.2 or Table 12.3.

11.19 Assessment of performance at minimum spacing and edge distance for adhesive and torque-controlled adhesive anchors:

11.19.1 Requirement for torque tests: The 5% fractile of the maximum recorded torque calculated according to Section 11.2 and normalized to f'_c = 2500 lb/in.^{2} (17.2 MPa) according to Section 11.1.2 shall be larger than:

1. the lesser of 1.7T_{inst} and 1.0T_{inst} + 100 ft-lb (135 Nm) for anchors to be designed assuming uncracked concrete conditions;
2. the lesser of 1.3T_{inst} and 1.0T_{inst} + 30 ft-lb (40 Nm) for anchors that are qualified for cracked concrete and are to be designed assuming cracked concrete conditions where the crack width is restrained by reinforcing in the concrete.

11.19.2 If these requirements are not met, determine c_{min} and s_{min} by either:

a. holding c_{min} constant and increase s_{min}, until the requirements are fulfilled; or
b. holding s_{min} constant, and increase c_{min}, until the requirements are fulfilled; or
c. increasing c_{min} and s_{min}, until the requirements are fulfilled.

11.19.3 Requirements for load tests: The concrete shall not crack during anchor installation. The mean failure load shall equal or exceed 90% of the expected load calculated on the basis of the service-condition tests in uncracked concrete, taking into account the effects of reduced spacing and edge distances.

11.19.4 Report the minimum edge and spacing distances and the associated minimum member thickness.

11.20 Assessment of shear capacity for anchor elements with non-uniform cross-section for adhesive and torque-controlled adhesive anchors:

11.20.1 Calculate and report the normalized characteristic steel shear capacity V_{st} in accordance with Section 11.1.3 and Section 0. When shear tests are not required, the anchor shear strength corresponding to anchor element failure shall be determined in accordance with Section 11.6.

11.21 Assessment of performance under seismic tension for adhesive and torque-controlled adhesive anchors):

11.21.1 All anchors in a test series shall complete the simulated seismic-tension load history specified in Table 9.2 and Fig. 9.4. Failure of an anchor to develop the required tension resistance in any cycle prior to completing the loading history specified in Table 9.2 and Fig. 9.4 shall be recorded as an unsuccessful test. The mean residual capacity of the anchors in the test series shall be equal to or greater than 160% of N_{eq} as given by Eq. 9.2.

11.21.1.1 Successful completion of the cyclic loading history and fulfillment of the residual tension capacity requirement of this Section shall be reported together with an anchor capacity in cracked concrete according to Section 11.3 for adhesive anchors and Section 11.4 for torque-controlled adhesive anchors in Table 12.2 or Table 12.3 for use in designing for load cases that include earthquake loading.

11.21.1.2 If the anchor fails to fulfill the above requirements at N_{eq}, it shall be permitted to conduct the test with reduced cyclic loads conforming to the loading history specified in Table 9.2 and Fig. 9.4 whereby $N_{eq,reduced}$, $N_{i,reduced}$ and $N_{m,reduced}$ are substituted for N_{eq}, N_i and N_m, respectively. All anchors in a test series shall complete the simulated seismic-tension load history. Failure of an anchor to develop the required tension resistance in any cycle prior to completing the loading history given Table 9.2 and Fig. 9.4 shall be recorded as an unsuccessful test. The mean residual capacity of the anchors in the test series in the tension test shall be at least 160% of the reduced peak load $N_{eq,reduced}$. Successful completion of the reduced cyclic loading history and fulfillment of the residual tension capacity requirement of this section shall be recorded together with the reduction factor $\alpha_{N,seis}$ as given by Eq. 11.37.

$$\alpha_{N,seis} = \frac{N_{eq,reduced}}{N_{eq}} \qquad \text{Eq. 11.37}$$

11.21.1.3 The reduction factor $\alpha_{N,seis}$ shall be used to determine $\tau_{k,seis}$ in accordance with Section 11.3.5.4 or $N_{k,p,seis}$ in accordance with Section 0. These values shall be reported in Table 12.2 or Table 12.3 for load combinations that include seismic loading.

11.22 Assessment of performance under seismic shear for adhesive and torque-controlled adhesive anchors:

11.22.1 Requirements: All anchors in a test series shall complete the simulated seismic-shear load history specified in Table 9.3 and Fig. 9.5. Failure of an anchor to develop the required shear resistance in any cycle prior to completing the loading history specified in Table 9.3 and Fig. 9.5 shall be recorded as an unsuccessful test. The mean residual capacity of the anchors in the test series shall be at least 160% of V_{eq} as given by Eq. 9.5 or Eq. 9.8.

11.22.1.1 Successful completion of the cyclic loading history and fulfillment of the residual shear capacity requirement of this Section shall be reported together with an anchor capacity V_s, equal to the characteristic value, V_{st}, determined from the static shear test results to be reported in Table 12.2 or Table 12.3 for use in cases that include earthquake loading.

11.22.1.2 If the anchor fails to fulfill the above requirements at V_{eq}, it shall be permitted to conduct the test with reduced cyclic loads conforming to the loading history specified in Table 9.3 and Fig. 9.5 whereby $V_{eq,reduced}$, $V_{i,reduced}$ and $V_{m,reduced}$ are substituted for V_{eq}, V_i and V_m, respectively. All anchors in a test series shall complete the simulated seismic-shear load history. Failure of an anchor to develop the required shear resistance in any cycle prior to completing the loading history given Table 9.3 and Fig. 9.5 shall be recorded as an unsuccessful test. The mean residual capacity of the anchors in the test series in the tension test shall be at least 160% of the reduced peak load $V_{eq,reduced}$. Successful completion of the reduced cyclic loading history and fulfillment of the residual shear capacity requirement of this Section shall be recorded together with a reduction factor $\alpha_{V,seis}$ as given by Eq. 11.38.

$$\alpha_{V,seis} = \frac{V_{eq,reduced}}{V_{eq}} \qquad \text{Eq. 11.38}$$

11.22.2 The reduction factor $\alpha_{V,seis}$ shall be used to determine $V_{s\ seis}$ in accordance with Section 11.6.4. This value shall be reported in Table 12.2 or Table 12.3 for load combinations that include seismic loading

11.22.3 For a given anchor diameter, all embedment depths greater than the tested embedment depth shall be qualified at the value of V_s determined in accordance with Section 11.20. Evaluation of V_s for embedment depths between the tested embedment depths shall be by linear interpolation. For anchor diameters not tested, the minimum value of $\alpha_{V,seis}$ from the adjacent tested anchor diameters shall be reported.

11.23 Establishment of hole cleaning procedures for adhesive and torque-controlled adhesive anchors:

11.23.1 Hole cleaning procedures shall correspond to the procedures used in the test program. If no hole cleaning is used, it shall be permitted to specify installation of the anchor without hole cleaning.

11.23.2 Hole cleaning procedures shall be reported. See Section 8.5.3

11.24 Establishment of on-site quality control and installation conditions for adhesive anchors:

11.24.1 For restrictions on installation conditions based on the level of on-site quality control and installation safety tests performed, see Table 11.10 and Table 11.11Table **11.11**. For the determination of the anchor category see Section 11.3.6.

11.24.2 Required installation conditions shall be reported.

Table 11.10 – Limitations on installation conditions for adhesive anchors installed under periodic special inspection only [1,2]

Installation conditions permitted	Table 4.1 or Table 4.2 installation safety tests performed			
	2a	2b	2c	2d
Installation shall be limited to dry indoor locations.	X			
Installation in exterior locations shall be permitted.	X	X		
Installation in water-filled holes shall be permitted.	X	X	X	
Installation in submerged concrete shall be permitted.	X			X

[1] See Section 14.0 for quality control requirements.
[2] See Table 11.13 for limitations on use.

Table 11.11 – Limitations on installation conditions for adhesive anchors installed under continuous special inspection and an on-site proof loading program [1,2,3]

Installation conditions permitted	Table 4.1 or Table 4.2 installation safety tests performed						
	2a	2b	2c	2d	2f	2g	2h
Installation shall be limited to dry indoor locations.	X						
Installation in exterior locations shall be permitted.	X	X			X		
Installation in water-filled holes shall be permitted.	X	X	X		X	X	
Installation in submerged concrete shall be permitted.	X			X			X

[1] See Section 14.0 for quality control requirements.
[2] See Table 11.13 for limitations on use.
[3] Omission of less severe tests is permitted in specific cases.

11.25 Establishment installation conditions for torque-controlled adhesive anchors:

For restrictions on installation conditions based on installation safety tests performed, see Table 11.12.

Table 11.12 – Limitations on installation conditions for torque-controlled adhesive anchors [1,2]

Installation conditions permitted	Table 4.3 or Table 4.4 installation safety tests performed				
	2a	2b	2c	2d	2e
Installation shall be limited to dry indoor locations.	X	X			
Installation in exterior locations shall be permitted.	X	X	X		
Installation in water-filled holes shall be permitted.	X	X	X	X	
Installation in submerged concrete shall be permitted.	X	X			X

[1] See Section 14.0 for quality control requirements.
[2] See Eq. 11.13 for limitations on use.

11.26 Assessment based on environmental conditions (adhesive and torque-controlled adhesive anchors):

11.26.1 For use restrictions based on environmental tests performed within the anchor assessment program, see Table 11.13.

11.26.2 Use restrictions shall be reported.

Table 11.13 – Limitations on use for adhesive anchors and torque-controlled adhesive anchors based on environmental conditions

Use conditions permitted		Reliability tests performed											
		Table 4.1			Table 4.2			Table 4.3			Table 4.4		
		3	9a	9b	6	13a	13b	6	13a	13b	6	12a	12b
Applications limited to dry interior environments without aggressive exposure conditions			X			X			X			X	
Applications in interior or exterior environments[1]	without aggressive exposure conditions [2]	X	X		X	X		X	X		X	X	
	with aggressive exposure conditions	X	X	X	X	X	X	X	X	X	X	X	X

[1] Use in exterior or aggressive exposure conditions is predicated on the appropriate steel type or coating.
[2] Classification predicated on exposure to alkaline environment but no exposure to sulfuric atmosphere.
[3] Classification predicated on exposure to alkaline environment and sulfuric atmosphere.

11.27 Assessment for installation direction:

11.27.1 If tests for the assessment of installation direction have been successfully performed, it shall be reported that the anchors shall be permitted to be installed in all orientations. If these tests have not been successfully performed, it shall be reported that the anchors are permitted to be installed in the down vertical direction only.

12.0 DATA PRESENTATION

12.1 General: The following information shall be submitted:

12.1.1 Product description:

12.1.1.1 Generic or trade name.

12.1.1.2 Manufacturer's catalog number.

12.1.1.3 Nominal thread size.

12.1.1.4 Anchor length.

12.1.1.5 Permitted manufacturing tolerances.

12.1.1.5.1 This information shall be held in strictest confidence by ICC-ES.

12.1.2 Basic materials, including appropriate physical properties before and after manufacture and protective coatings, shall be described. If the anchor consists of component parts involving different materials, differences shall be noted.

12.1.3 Appropriate National Standards for the anchor constituent materials: Reports of physical properties for materials used in test specimens shall be submitted. The reports shall be generated by a mill or accredited testing laboratory. Where actual material strength exceeds the specified minimum strength, test results shall be adjusted to the specified minimum strength of the anchor material. Where no physical property specification exists, acceptable properties for quality control purposes shall be established by physical property tests.

12.1.4 Installation instructions: Manufacturer's published installation instructions, as well as published instructions for application and design shall be submitted.

12.1.5 Packaging and identification: Information on anchor packaging and identification shall be determined and reported in accordance with Section 6.0 of this criteria. The methods of packaging shall be described. The manufacture's name or insignia, and the anchor types and size shall be marked either directly on the anchor or on the packaging units. In addition, the evaluation report number (ESR-XXXX) and name of the inspection agency shall appear on the packaging units.

12.1.6 Field preparation: Information concerning methods of preparing anchors and concrete for installation shall be described.

12.2 Data analysis:

12.2.1 Perform analysis in accordance with Section 10.0 to assess the results of testing of the subject anchor system in conformance with this criteria.

12.3 Test reports:

12.3.1 Test reports shall comply with the ICC-ES Acceptance Criteria for Test Reports (AC85).

12.3.2 Test reports shall include information described in Section 13 of ASTM E 488.

12.3.3 Test reports shall also include the following:

12.3.3.1 Mode of failure for each test (e.g., steel rupture, concrete splitting, concrete cone failure, anchor pullout, anchor pull-through).

12.3.3.2 Photographs of test equipment and typical anchor failure modes.

12.3.3.3 Report approval by a registered design professional.

12.3.3.4 Verification that test specimen sampling complies with Section 5.1.

12.3.3.5 Manufacturer's published installation instructions, including minimum hole cleaning procedures and equipment.

12.3.4 Report the data required by this criteria in the format shown in Table 12.1, Table 12.32, or Table 12.3. Add other observations as appropriate, and include them in the evaluation report.

12.4 Evaluation report:

12.4.1 The evaluation report shall include sufficient information for complete product identification, manufacturer's printed installation instructions, and design data.

12.4.2 The evaluation report shall also include:

12.4.2.1 Description of anchors;

12.4.2.2 Constituent materials;

12.4.2.3 Markings;

12.4.2.4 Anchor performance data in accordance with this criteria as reported in Table 12.1, Table 12.2, or Table 12.3;

12.4.2.5 Design requirements in accordance with this criteria; and

12.4.2.6 Special inspection requirements.

12.4.3 Findings shall include the following as applicable:

12.4.3.1 Limitations on installation conditions in accordance with Table 11.10, Table 11.11 or Table 11.12.

12.4.3.2 Limitations on use based on environmental conditions in accordance with Table 11.13.

12.4.3.3 Cracked concrete:

12.4.3.3.1 (*This version applies where the anchor has been qualified in accordance with Table 4.1.*) Anchors are limited to installation in concrete that is uncracked and may be expected to remain uncracked for the service life of the anchor. Cracking shall be assumed to occur when, under service loads or imposed deformations, the tensile stress in the concrete exceeds the modulus of rupture f_r.

12.4.3.3.2 (*This version applies where the anchor has been qualified in accordance with Table 4.2, Table 4.3, or Table 4.4.*) Anchors are permitted to be installed in concrete that is cracked or may be expected to crack during the service life of the anchor.

12.4.3.4 Fatigue and shock loading: Since an ICC-ES acceptance criteria for evaluating data to determine the performance of anchors subjected to fatigue or shock loading is unavailable at this time, the use of the subject anchors to resist load combinations that include fatigue or shock loading is beyond the scope of this report.

12.4.3.5 Fire resistive construction: Anchors are not permitted to support fire-resistive construction. Where not otherwise prohibited by the code, anchors are permitted for installation in fire-resistive construction provided that at least one of the following conditions is fulfilled:

- Anchors are used to resist wind or seismic forces only, or
- Anchors that support gravity load bearing structural elements are within a fire-resistive envelope or a fire-resistive membrane, are protected by approved fire-resistive materials, or have been evaluated for resistance to fire exposure in accordance with recognized standards, or
- Anchors are used to support non-structural elements.

12.4.3.6 Earthquake resistance:

12.4.3.6.1 (This version applies where the anchor has been qualified in accordance with Table 4.1 or the seismic resistance has not been verified in accordance with this criteria.) Load combinations including earthquake loads are not permitted.

12.4.3.6.2 (This version applies where seismic resistance has been verified in accordance with this criteria.) Load combinations including earthquake loads are permitted.

Table 12.1 – Sample format for reporting adhesive anchor data for anchors qualified for use in uncracked concrete only

Anchor qualified per Table 4.1 —Test program for evaluating adhesive anchor systems for use in uncracked concrete										
Anchor Manufacturer	Anchor Name[1]	Criteria and Code(s)	Symbol	Criteria Section of Reference Standard[2]	Units[3]	Anchor nominal diameters				
Anchor diameter			d_o		in.					
Installation torque[4]			T_{inst}		ft-lb					
Effective bolt tension area			A_{se}		in.^{2}					
Strength reduction factor for tension, steel failure modes			ϕ		-					
Strength reduction factor for shear, steel failure modes			ϕ		-					
Anchor bolt	Minimum specified yield strength		f_y	ASTM F606	lb/in.^{2}					
	Minimum specified ultimate strength		f_{ut}	ASTM F606	lb/in.^{2}					
	Bolt steel elongation at break			ASTM F606	%					
	Bolt steel cross-section reduction at break			ASTM F606	in.^{2}					
Nominal steel strength of a single anchor loaded in tension			N_s		lb					
Nominal steel strength of a single anchor loaded in shear			V_s		lb					
Embedment depth(s)			h_{ef}		in.					
Effectiveness factor - uncracked concrete[6]			k_{uncr}		-					
Anchor category continuous sp. insp.[7]			-		-					
Anchor category periodic sp. insp.			-		-					
Characteristic bond resistance in uncracked concrete[8]			$\tau_{k,uncr}$		lb/in.^{2}					
Strength reduction factor for tension, concrete failure modes[5]			ϕ	Cond. A	-					
				Cond. B	-					
Strength reduction factor for shear, concrete failure modes[5]			ϕ	Cond. A	-					
				Cond. B	-					
Adjustment for temperature category B			$K_{temp\ B}$		-					
Adjustment for exposure to sulfur			K_{sulfur}		-					
Minimum member thickness			h_{min}		in.					
Minimum anchor spacing			s_{min}		in.					
Minimum edge distance			c_{min}		in.					

[1] Trade name. For anchors distributed under multiple trade names, list all.

[2] ASTM or ISO Standards.

[3] Fractional units shown. SI units may also be used.

[4] Manufacturer's recommended torque as applicable for torque-controlled adhesive anchors.

[5] For use with the load combinations of IBC Section 1605.2.1. or ACI 318 Section 9.2. Condition A applies where the potential concrete failure surfaces are crossed by supplementary reinforcement proportioned to tie the potential concrete failure prism into the structural member. Condition B applies where such supplementary reinforcement is not provided, or where pullout or pryout strength governs.

[6] $\Psi_{c,n}$ = 1.0 for all cases.

[7] Includes proof load program.

[8] Provide two bond resistances in Table 12.1: one for load combinations that include sustained loads, where bond resistance is calculated in accordance with Eq. 11.12 including α_p; and one for short-term loading only such as wind, where bond resistance is calculated in accordance with Eq. 11.12 but without α_p.

Table 12.2 – Sample format for reporting adhesive anchor data for anchors qualified for use in both cracked and uncracked concrete

Anchor qualified per Table 4.2—Test program for evaluating adhesive anchor systems for use in cracked and uncracked concrete															
Anchor Manufacturer	Anchor Name[1]	Criteria and Code(s)	Symbol	Criteria Section of Reference Standard[2]	Units[3]	Anchor nominal diameters									
Bolt diameter			d_b		in.										
Installation torque[4]			T_{inst}		ft-lb										
Effective bolt tension area			A_{se}		in.^{2}										
Sleeve cross-sectional area			A_{sl}		in.^{2}										
Strength reduction factor for tension, steel failure modes			ϕ		-										
Strength reduction factor for shear, steel failure modes			ϕ		-										
Anchor bolt	Minimum specified yield strength		f_y	ASTM F606	lb/in.^{2}										
	Minimum specified ultimate strength		f_{ut}	ASTM F606	lb/in.^{2}										
	Bolt steel elongation at break			ASTM F606	%										
	Bolt steel cross-section reduction at break			ASTM F606	in.^{2}										
Nominal steel strength of a single anchor loaded in shear			V_k		lb										
Embedment depth(s)			h_{ef}		in.										
Anchor category continuous sp. insp.[6]			-		-										
Anchor category periodic sp. insp.			-		-										
Effectiveness factor - uncracked concrete			k_{uncr}		-										
Effectiveness factor - cracked concrete			k_{cr}		-										
k_{uncr}/k_{cr}			$\Psi_{c,N}$		-										
Characteristic bond resistance in uncracked concrete[7]			$\tau_{k,uncr}$		lb/in.^{2}										
Characteristic bond resistance in cracked concrete[7]			$\tau_{k,cr}$		lb/in.^{2}										
Strength reduction factor for tension, concrete failure modes[5]			ϕ	Cond. A	-										
				Cond. B	-										
Strength reduction factor for shear, concrete failure modes[5]			ϕ	Cond. A	-										
				Cond. B	-										
Adjustment for temperature category B			$\kappa_{temp\ B}$		-										
Adjustment for exposure to sulfur			κ_{sulfur}		-										
Minimum member thickness			h_{min}		in.										
Minimum anchor spacing			s_{min}		in.										
Minimum edge distance			c_{min}		in.										
Optional simulated seismic tests															
Adjustment for seismic tension loading			$\kappa_{seismic}$		-										
Nominal strength of a single anchor for seismic shear loading			$V_{k,seis}$		lb										

[1] Trade name. For anchors distributed under multiple trade names, list all.
[2] ASTM or ISO Standards.
[3] Fractional units shown. SI units may also be used.
[4] Manufacturer's recommended torque as applicable for torque-controlled adhesive anchors.
[5] For use with the load combinations of IBC Section 1605.2.1 or ACI 318 Section 9.2. Condition A applies where the potential concrete failure surfaces are crossed by supplementary reinforcement proportioned to tie the potential concrete failure prism into the structural member. Condition B applies where such supplementary reinforcement is not provided, or where pullout or pryout strength governs.
[6] Includes proof load program.
[7] Provide two bond resistances for each of the bond resistance values $\tau_{k,uncr}$ and $\tau_{k,cr}$ in Table 12.2: one for load combinations that include sustained loads, where bond resistance is calculated in accordance with Eq. 11.12 including α_p; and one for short-term loading only such as wind, where bond resistance is calculated in accordance with Eq. 11.12 but without α_p.

Table 12.3 – Sample format for reporting torque-controlled adhesive anchor data for anchors qualified for use in both cracked and uncracked concrete

Anchor qualified per Table 4.3 (Table 4.4)—Test program for evaluating torque-controlled adhesive anchor systems for use in cracked and uncracked concrete

Anchor Manufacturer	Anchor Designation[1]	Criteria and Code(s)	Symbol	Criteria Section of Reference Standard[2]	Units[3]	Anchor nominal diameters									
Bolt diameter			d_b		in.										
Installation torque[4]			T_{inst}		ft-lb										
Effective bolt tension area			A_{se}		in.^{2}										
Strength reduction factor for tension, steel failure modes			ϕ		-										
Strength reduction factor for shear, steel failure modes			ϕ		-										
Anchor bolt	Minimum specified yield strength		f_y	ASTM F606	lb/in.^{2}										
	Minimum specified ultimate strength		f_{ut}	ASTM F606	lb/in.^{2}										
	Bolt steel elongation at break			ASTM F606	%										
	Bolt steel cross-section reduction at break			ASTM F606	in.^{2}										
Nominal strength of a single anchor loaded in shear as governed by steel rupture			V_k		lb										
Embedment depth(s)			h_{ef}		in.										
Anchor category			-		-										
Effectiveness factor – uncracked concrete			K_{uncr}		-										
Effectiveness factor – cracked concrete			k_{cr}		-										
k_{uncr}/k_{cr}			$\Psi_{c,N}$		-										
Characteristic pullout resistance in uncracked concrete[6]			$N_{p,uncr}$		lb										
Characteristic pullout resistance in cracked concrete[6]			$N_{p,cr}$		lb										
Strength reduction factor for tension, concrete failure modes[5]			ϕ	Cond. A	-										
				Cond. B	-										
Strength reduction factor for shear, concrete failure modes[5]			ϕ	Cond. A	-										
				Cond. B	-										
Minimum member thickness			h_{min}		in.										
Adjustment for temperature category B			$K_{temp\ B}$		-										
Adjustment for exposure to sulfur			K_{sulfur}		-										
Minimum anchor spacing			s_{min}		in.										
Minimum edge distance			c_{min}		in.										
Optional simulated seismic tests															
Pullout resistance for seismic loading			$N_{k,seis}$		lb										
Nominal strength of a single anchor for seismic shear loading			$V_{k,seis}$		lb										

[1] Trade name. For anchors distributed under multiple trade names, list all.

[2] ASTM or ISO Standards.

[3] Fractional units shown. SI units may also be used.

[4] Manufacturer's recommended torque as applicable for torque-controlled adhesive anchors.

[5] For use with the load combinations of IBC Section 1605.2.1 or ACI 318 Section 9.2. Condition A applies where the potential concrete failure surfaces are crossed by supplementary reinforcement proportioned to tie the potential concrete failure prism into the structural member. Condition B applies where such supplementary reinforcement is not provided, or where pullout or pryout strength governs.

[6] Provide two pullout resistances for each of the pullout resistance values $N_{p,uncr}$ and $N_{p,cr}$ in Table 12.3: one for load combinations that include sustained loads, where pullout resistance is calculated in accordance with Eq. 11.23 including α_p; and one for short-term loading only such as wind, where pullout resistance is calculated in accordance with Eq. 11.23 but without α_p.

13.0 REQUIREMENTS FOR THE INDEPENDENT TESTING AND EVALUATION AGENCY

13.1 General:

13.1.1 The testing and assessment of anchors under this criteria shall be performed by an independent testing and evaluation agency (ITEA) listed by a recognized accreditation service conforming to the requirements of ISO 17025. In addition to these standards, listing of the ITEA shall be predicated on documented experience in the testing and evaluation of anchors according to ASTM E 488, ACI 355.2, and this criteria.

13.2 Testing laboratories:

13.2.1 As a source of test reports, testing laboratories shall comply with Section 2.0 of the ICC-ES Acceptance Criteria for Test Reports (AC85) and Section 4.2 of the ICC-ES Rules of Procedure for Evaluation Reports. The primary testing laboratory shall verify that all elements of the test program and analysis are in compliance with this criteria.

13.3 Testing by Independent Testing and Evaluation Agency and Manufacturer

13.3.1 The required minimum number of reference, reliability, supplemental, and at least 50 percent of the service-condition test series given in Table 4.1, 4.2, 4.3 or 4.4 of this criteria shall be performed by the independent testing and evaluation agency (Section 13.1.1) in their facility. Not more than 50 percent of the test for each conducted service-condition test series required by Table 4.1, 4.2, 4.3, or 4.4 of this criteria are permitted to be performed by the manufacturer. All such tests shall be witnessed by an independent, accredited testing laboratory (Section 13.1.1 and 13.2.1).

13.3.2 Additional results of tests performed by the manufacturer shall be permitted to be considered in the evaluation. All tests performed by the manufacturer shall be permitted to be considered only if the results are statistically equivalent to those of the independent testing and evaluation agency (Section 2.1.19). The number of tests conducted by the manufacturer shall not exceed the number of tests by the independent accredited testing laboratory.

13.4 Certification:

13.4.1 The testing shall be certified by a licensed engineer employed or retained by the independent testing and evaluation agency.

14.0 QUALITY CONTROL REQUIREMENTS

14.1 Quality control manuals:

14.1.1 For each product assessed in accordance with this criteria, quality documentation complying with the ICC-ES Acceptance Criteria for Quality Documentation (AC10) shall be submitted. The quality documentation shall include all installed components of the anchor system as provided by the manufacturer. For torque-controlled adhesive anchors, the quality documentation shall include the anchor element.

14.2 Quality-assurance program:

14.2.1 Anchors shall be manufactured under an approved quality-assurance program with follow-up inspections by an inspection agency accredited by the *International Accreditation Service* (IAS) under ISO 17020 or as otherwise acceptable to ICC-ES.

14.2.2 Inspections shall assess conformance of ongoing production with the quality documentation on file with including review of most recent fingerprinting test results in accordance with Section 6.3.

14.3 Special inspection:

14.3.1 Special inspection shall be provided in accordance with Chapter 17 of the IBC or UBC and in accordance with this criteria. For each type of anchoring system, the manufacturer shall submit inspection procedures to verify proper usage. For all cases where overhead installation (vertical up) and designed to resist sustained tension loads, continous special inspection shall be required.

14.3.2 Continuous special inspection: Where required, a program for continuous special inspection shall conform to the following additional requirements:

14.3.2.1 The special inspector shall observe all aspects of the anchor installation.
14.3.2.1.1 Exception: Holes shall be permitted to be drilled in the absence of the special inspector provided the special inspector examines the drill bits used for the drilling and verifies the hole sizes.

14.3.2.2 As a minimum, the following items shall be verified:

1. hole drilling method in accordance with manufacturer's printed installation instructions;
2. hole location, diameter and depth;
3. hole cleaning in accordance with manufacturer's printed installation instructions;
4. anchor element type, material, diameter and length;
5. adhesive identification and expiration date;
6. adhesive installation in accordance with manufacturer's printed installation instructions.

14.3.3 Periodic special inspection: Where required, a program for periodic special inspection shall conform to the following additional requirements:

14.3.3.1 The special inspector shall verify the initial installations of each type and size of adhesive anchor by construction personnel on site in accordance with Section 14.3.2.2. Subsequent installations of the same anchor type and size by the same construction personnel shall be permitted to be performed in the absence of the special inspector. Any change in the anchor product being installed or the personnel performing the installation shall require an initial inspection in accordance with Section 14.3.2.2. For ongoing installations over an extended period the special inspector shall make regular inspections to confirm correct handling and installation of the product.

14.3.4 Proof loading program: Where required, a program for on-site proof loading (proof loading program) to be conducted as part of the special inspection shall conform to the following minimum requirements:

14.3.4.1 The proof loading program shall be established by the engineer or design professional of record. As a minimum, the following requirements shall be addressed in the proof loading program:

1. frequency of proof loading based on anchor type, diameter, embedment;
2. proof loads by anchor type, diameter, embedment and location;
3. acceptable displacements at proof load;
4. remedial action in the event of failure to achieve proof load or excessive displacement.

14.3.4.2 Unless otherwise directed by the engineer or design professional of record, proof loads shall be applied as confined tension tests (see Fig. 5.). Proof load levels shall not exceed the lesser of 50% of expected ultimate load based on adhesive bond strength nor 80% of the anchor yield strength. The proof load shall be maintained at the required load level for a minimum of 10 seconds.

14.4 Product modifications:

14.4.1 Prior to implementing any substantive modification to an anchor system which has previously been assessed according to this criteria, the manufacturer shall report the nature and significance of the modification to the independent testing and evaluation agency (see Section 13.0).

14.4.2 For all modifications that are determined to have the potential to affect anchor performance, the testing and evaluation agency shall perform the requisite reference and reliability tests to assess the impact of the modification. If the modified product can be shown to be statistically equivalent to those of the originally tested product, no additional testing shall be required. Otherwise, the modified product shall be tested in accordance with Table 4.1, Table 4.2, Table 4.3, or Table 4.4 as applicable.

ANNEX A – SUPPLEMENTAL ACCEPTANCE CRITERIA FOR EXISTING TEST DATA DEVELOPED IN ACCORDANCE WITH AC58

A.1.0 GENERAL

A.1.1 Scope

A.1.1.1 Annex 1 provides guidance for the evaluation of existing test data developed in accordance with AC58, ASTM E 488-96 and ASTM E 1512-93 for the purpose of satisfying the requirements of this criteria. Only existing test data addressed in this Section shall be considered for use with this criteria.

A.1.1.2 Only test data generated prior to January 1, 2006 shall be considered for use with this criteria.

A.1.2 Reference standards

A.1.2.1 ICC Evaluation Service (ICC-ES):

A.1.2.1.1 AC58 Acceptance Criteria for Adhesive Anchors in Concrete and Masonry Elements

A.1.2.2 ASTM International Standards

A.1.2.2.1 ASTM E 1512-93

A.1.2.2.2 ASTM E 488-96

A.2.0 DEFINITIONS AND NOTATION

A.2.1 Definitions

A.2.1.1 The following definitions are supplemental to those provided in Section 2.1.

A.2.1.2 **Existing test data** – Test data resulting from testing conducted in accordance with AC58 between January 1, 1995 and January 1, 2006.

A.2.1.3 **AC58 test series** – See **Existing test data**.

A.2.2 Notation

A.2.2.1 The following notation is supplemental to that provided in Section 2.2.

$N_{u,f_c,test}$ = ultimate tension load from testing in accordance with AC58, lb (N).

N_{u,f_c} = ultimate tension load adjusted for support spacing, lb (N).

$\frac{\alpha}{\alpha_{req}}$ = term used in the evaluation of the characteristic bond resistance in accordance with Eq. 11.12.

α_{sup} = adjustment factor in accordance with Fig. A.3.1 to account for support spacing.

$\bar{\tau}_{u,test}$ = the mean bond strength corresponding to an AC58 test series to be considered for use in conjunction with this criteria, psi (MPa).

$\tau_{u,max}$ = the maximum bond stress corresponding to concrete breakout in accordance with Eq. A.3.2, psi (MPa).

Δ_{lim} = displacement corresponding to N_{adh}, in. (mm).

$\Delta_{service}$ = extrapolated estimate of the total displacement over the anchor intended service life, in. (mm).

A.3.0 SERVICE-CONDITION TESTS

A.3.1 Tension tests

A.3.1.1 Test results in accordance with AC58 as shown in Table A.3.1 may be employed for the assessment for the service-condition tension strength in accordance with this criteria.

Table A.3.1 – Supplemental conditions for use of AC58 service-condition tension test results

AC58 Test Series Number	AC58 Test Description	AC58 Nominal Concrete Compressive Strength	AC58 Test Conditions	Supplemental Conditions for Use with this Criteria	Remarks
1	Single anchors	Minimum	Anchors tested without edge and spacing influence	§A.3.1.2 §A.3.1.3	None
2	Single anchors	Medium			
3	Single anchors	Maximum			
4	Single anchors, critical edge distance	Minimum	$c = c_{cr}$	§A.3.1.2 §A.3.1.3	No adjustment for reduced edge distance permitted [a]
5	Single anchors, minimum edge distance	Minimum	$c = c_{min}$	§A.3.1.2 §A.3.1.3	No adjustment for edge distance permitted [a,b,d]
6	Single anchors, critical edge distance	Maximum	$c = c_{cr}$	§A.3.1.2 §A.3.1.3	No adjustment for edge distance permitted [a]
7	Single anchors, minimum edge distance	Maximum	$c = c_{min}$	§A.3.1.2 §A.3.1.3	No adjustment for edge distance permitted [a,b,d]
8	Group of two anchors, critical spacing s_{cr}	Minimum	$s = s_{cr}$	§A.3.1.2 §A.3.1.3	Divide recorded ultimate load by 2 to obtain single anchor capacity [c]
9	Group of two anchors, minimum spacing distance	Minimum	$s = s_{min}$	§A.3.1.2 §A.3.1.3	Divide recorded ultimate load by 2 to obtain single anchor capacity [b,c,d]
10	Group of four anchors, critical spacing s_{cr}	Minimum	$s = s_{cr}$	§A.3.1.2 §A.3.1.3	Divide recorded ultimate load by 4 to obtain single anchor capacity [c]
11	Group of four anchors, minimum spacing distance	Minimum	$s = s_{min}$	§A.3.1.2 §A.3.1.3	Divide recorded ultimate load by 4 to obtain single anchor capacity [b,c,d]

Notes

a. These results may not be substituted for corner tests in accordance with AC308 (paragraph 9.9).
b. These results may not be substituted for splitting tests in accordance with AC308 (paragraph 9.10).
c. Tension tests to establish the capacity of anchor groups are not required by this criteria. The results of such testing may only be used for the establishment of the service-condition tension capacity as noted.
d. Use of these values for the determination of the service-condition tension capacity may be overly conservative.

A.3.1.2 Adjustment for support spacing: Tension test results associated with a support spacing of $2h_{ef}$ shall be adjusted in accordance with this section.

A.3.1.2.1 Calculate the mean bond stress value for the test series under consideration in accordance with Eq. A.3.1.

$$\bar{\tau}_{u,test} = \frac{\bar{N}_{u,f_c,test}}{\pi \cdot d \cdot h_{ef}} \quad \text{Eq. A.3.1}$$

A.3.1.2.2 Calculate the maximum bond stress corresponding to concrete breakout in accordance with Eq. A.3.2.

$$\tau_{u,max} = \frac{k_c}{\pi \cdot d}\sqrt{h_{ef} \cdot f_{c,test}} \quad \text{Eq. A.3.2}$$

Where

k_c = 24

A.3.1.2.3 Adjust the tension test results in accordance with Eq. A.3.3.

$$N_{u,f_c} = \alpha_{sup} \cdot N_{u,f_c,test} \quad \text{Eq. A.3.3}$$

Where

α_{sup} = adjustment factor in accordance with Fig. A.3.1 to account for support spacing.

$N_{u,f_c,test}$ = ultimate tension load from tests in accordance with AC58.

N_{u,f_c} = ultimate tension load adjusted for support spacing.

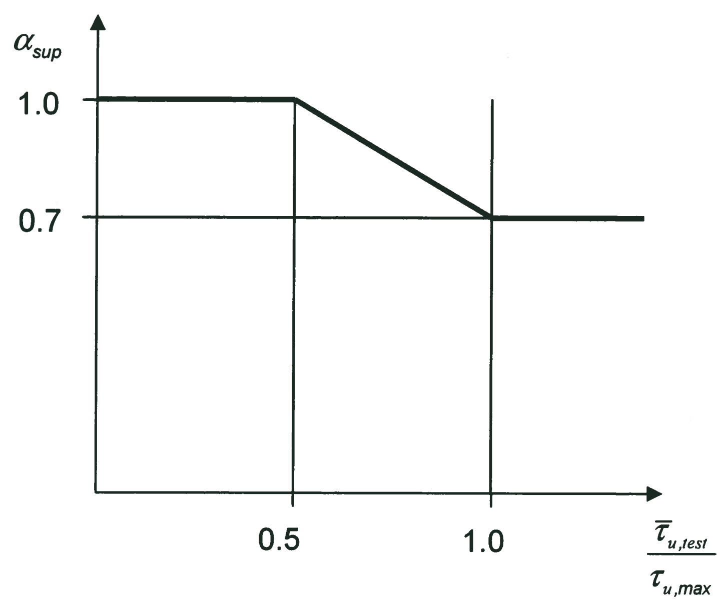


Fig. A.3.1 – Adjustment factor α_{sup} for use in Eq. A.3.3

A.3.1.3 Adjustment for concrete strength: Adjust the values of N_{u,f_c} for the actual concrete strength used in the tests in accordance with Table A.3.2

Table A.3.2 –Adjustment of tension test results for concrete strength

Nominal specified strength of concrete used for test	AC308 concrete strength class in accordance with Section 5.2.5 for which recorded ultimate loads may be used	Adjustment of recorded ultimate loads.
$f_c \leq$ 2,500 psi ($f_c \leq$ 17 MPa)	Low-strength concrete 2,500 – 4,000 psi (17 to 28 MPa)	No adjustment of recorded ultimate loads permitted.
2,500 < $f_c \leq$ 4,000 psi (17 MPa < $f_c \leq$ 28 MPa)	Low-strength concrete 2,500 – 4,000 psi (17 to 28 MPa)	Normalize recorded ultimate loads to 2,500 psi (17 MPa) in accordance with Section 11.1.2.1 whereby *n* shall be taken as 0.5.
f_c > 4,000 psi (f_c > 28 MPa)	High strength concrete 6,500 – 8,500 psi (46 to 60 MPa)	No adjustment of recorded ultimate loads permitted.

A.3.2 Shear tests

A.3.2.1 Test results in accordance with AC58 as shown in Table A.3.3 may be employed for the assessment for the service-condition shear strength where required in accordance with this criteria.

Table A.3.3 – Supplemental conditions for use of AC58 service-condition shear test results

<table>
<tr><th>AC58 Test Series Number</th><th>AC58 Test Description</th><th>AC58 Nominal Concrete Compressive Strength</th><th>AC58 Test Conditions</th><th>Supplemental Conditions for Use with this Criteria</th><th>Remarks</th></tr>
<tr><td>12</td><td>Single anchors</td><td>Minimum</td><td>-</td><td rowspan="3">None</td><td>None</td></tr>
<tr><td>13</td><td>Single anchors, critical edge distance</td><td>Minimum</td><td>$c = c_{cr}$</td><td>No adjustment of recorded ultimate loads permitted. [a]</td></tr>
<tr><td>14</td><td>Single anchors, minimum edge distance</td><td>Minimum</td><td>$c = c_{min}$</td><td>No adjustment of recorded ultimate loads permitted. [a,b]</td></tr>
</table>

Notes

a. Use of tests resulting in concrete failure may be overly conservative.

b. Use of these values for the determination of the service-condition steel shear capacity may be overly conservative.

A.3.3 Oblique tests

A.3.3.1 Results of oblique tension tests performed in accordance with AC58 (AC58 test series number 15) may not be used in conjunction with this criteria.

A.4.0 SUITABILITY TESTS

Table A.4.4 – Supplemental conditions for use of AC58 suitability test results

AC58 Test Series Number	AC58 Test Description	AC58 Nominal Concrete Compressive Strength	AC58 Test Conditions	Supplemental Conditions for Use with this Criteria	Remarks
16	Fire resistive	$3,000 \pm 500$ psi	Section 7.1, 7.8 ASTM E 1512-93	§A.4.1	Not useable
17	Creep	$3,000 \pm 500$ psi	Section 7.1, 7.5 ASTM E 1512-93	§A.4.2	Useable in conjunction with Table 4.1, Test No. 4 and Table 4.2, Test No. 7
18	In-Service temperature	$3,000 \pm 500$ psi	Section 7.1, 7.6 ASTM E 1512-93	§A.4.3	Useable in conjunction with Table 4.1, Test Nos. 8a and 8b and Table 4.2, Test Nos. 12a and 12b, Table 4.3, Test Nos. 12a and 12b, Table 4.4, Test Nos. 11a and 11b
19	Dampness	$3,000 \pm 500$ psi	Section 7.1, 7.7 ASTM E 1512-93	§A.4.4	Useable in conjunction with Table 4.1, Test No. 2g and Table 4.2, Test No. 2g
20	Freezing and thawing	$4,500 \pm 1000$ psi	Section 7.1, 7.9 ASTM E 1512-93	§A.4.5	Not useable
21	Seismic	$3,000 \pm 500$ psi	-	§A.4.6	Not useable

A.4.1 Fire resistance tests

A.4.1.1 Tests performed in accordance AC58 Section 5.3.2 and ASTM E 1512-93 may not be used in conjunction with this standard.

A.4.2 Creep tests

A.4.2.1 Creep tests conducted in accordance with AC58 Section 5.3.3 and ASTM E 1512-93 and ASTM E 488-96 may be used for the assessment of creep performance at long-term elevated temperature in accordance with this criteria (Table 4.1, Test No. 4 and Table 4.2, Test No. 7).

A.4.2.2 The extrapolation and assessment of creep displacement and residual capacity shall be in accordance with Section 11.12 and this section.

A.4.2.3 Creep tests including residual tension testing: Where residual tension testing has been performed in conjunction with the creep tests, the creep data may be utilized for the assessment in accordance with this criteria without amendment.

A.4.2.3.1 If the number of tests in a test series is n = 3, and the coefficient of variation of the tests for residual capacity is greater than 15%, then the reduction factor α_{cov} shall be evaluated in accordance with Eq. 11.6, with the COV term set equal to 15%.

A.4.2.4 Creep tests without residual tension testing: Where residual tension tests have not been performed in conjunction with the creep tests, the value of $\frac{\alpha}{\alpha_{req}}$ for assessment in accordance with Section11.3.5.3 shall be established in accordance with Table A.4.5.

Table A.4.5 – Establishment of $\frac{\alpha}{\alpha_{req}}$ for creep test data that does not include residual tension testing

Test configuration for creep test and associated reference tests [a]	Confined			Unconfined		
$\frac{\Delta_{service}}{\Delta_{lim}}$ [b]	≤ 0.8	> 0.8 < 1.0	1.0	≤ 0.7	> 0.7 < 1.0	1.0
$\frac{\alpha}{\alpha_{req}}$	1.0	linear interpolation	0.8	1.0	linear interpolation	0.7

[a] Tests conducted in accordance with ASTM E 488-96, ASTM E 1512-93 Section 7.1.2 and AC58.
[b] See Section 11.12.

A.4.3 In-service temperature tests

A.4.3.1 In-service temperature tension tests conducted in accordance with AC58 Section 5.3.4 and ASTM E 1512-93 Sections 7.6.1 to 7.6.3 and ASTM E 488-96 may be used for the assessment of tension capacity at elevated and reduced temperature (Table 4.1, Test Nos. 8a and 8b and Table 4.2, Test Nos. 12a and 12b, Table 4.3, Test Nos. 12a and 12b, Table 4.4, Test Nos. 11a and 11b) in accordance with this criteria.

A.4.3.2 The relationship between the maximum short-term temperature and the maximum long-term temperature must conform to the requirements of Table 9.1.

A.4.3.3 The maximum long-term temperature shall be equivalent to the temperature used in the sustained load tests at long-term elevated temperature (see Section 8.18.4).

A.4.3.4 In-service temperature tension tests conducted in accordance with ASTM E 1512-93 Section 7.6.5.1 and ASTM E 488-96 may be used for the assessment of the minimum cure time at decreased installation temperature in accordance with Section 9.6.2.1 of this criteria.

A.4.4 Dampness tests

A.4.4.1 Dampness tension tests conducted in accordance with AC58 Section 5.3.5 and ASTM E 1512-93 Sections 7.1 to 7.3 may be used for the assessment of the effect the sensitivity to installation in saturated concrete with hole cleaning performed in accordance with the manufacturer's published installation instructions (Table 4.1, Test No. 2f and Table 4.2, Test No. 2f). In order to account for differences in the conduct of the tests, a reduction factor of 0.8 shall be applied to the recorded failure loads.

A.4.4.2 Dampness tension tests conducted in accordance with ASTM E 1512-93 Sections 7.7.1 and 7.7.4 may be used for the assessment of the effect the sensitivity to installation in a water-filled hole with hole cleaning performed in accordance with the manufacturer's published installation instructions (Table 4.1, Test No. 2g and Table 4.2, Test No. 2g). In order to account for differences in the conduct of the tests, a reduction factor of 0.8 shall be applied to the recorded failure loads.

A.4.5 Freezing and thawing tests

A.4.5.1 Tests performed in accordance with AC58 Section 5.3.6 and ASTM E 1512-93 Section 7.1 and 7.9 may not be used in conjunction with this criteria.

A.4.6 Seismic tests

A.4.6.1 Simulated seismic tests performed in accordance with AC58 Section 5.3.7 may not be used in conjunction with this criteria.

A.5.0 SUPPLEMENTAL REQUIREMENTS

A.5.1 Round-robin tests

A.5.1.1 A unique value of α_{conc} to be applied to AC58 test results shall be evaluated in accordance with Section 11.3.1 whereby the value of $\overline{\tau}_{ref,f_c}$ shall be derived from round-robin testing conducted in accordance with Section 10.1 and the value of $\overline{\tau}_{u,f_c}$ shall be taken as the mean bond strength corresponding to the AC58 tension test series to be used in the assessment, normalized to concrete strength f_c=3,000 psi (21 MPa) in accordance with Section 11.1.

SMITH-EMERY LABORATORIES
An Independent Commercial Testing Laboratory
781 E. Washington Boulevard - 2nd Floor Los Angeles, California 90021 ◆ (213) 745-5333 ◆ Fax (213) 749-7232

Project No.: 38396-1

May 11, 2009

Andrew Butler
Precision Castings of Tennessee, Inc.
430 Calvert Drive
Gallatin, TN 37066

Subject: Cable-Tite Tie-Down System Testing

Dear Mr. Butler:

At your request, testing was conducted on the submitted your *Cable-Tite* tie-down system to evaluate its tension load strength and elongation properties in accordance with ICC-ES AC369, *Acceptance Criteria for Steel Assemblies,* effective March 1, 2007. Testing was conducted at Smith-Emery facility from April 7 to May 4, 2009. The attached Report Number L-09-830 presents a description of the testing performed, results, observations and any findings.

We appreciate this opportunity to be of service to you. If you have any questions regarding this report, please do not hesitate to contact us at your convenience.

Respectfully submitted,
SMITH EMERY LABORATORIES, INC.

Pingsheng Zhu
Registered Civil Engineer No. C72482
Registration Expires 6-30-10
Staff Engineer

Review and approved by,

V. Andrew Tan, P.E.
Director of Laboratories

Attachment: Report No. L-09-830

SMITH EMERY LABORATORIES

781 E. WASHINGTON BLVD. • LOS ANGELES, CA 90021
PHONE (213) 749-3411 • FAX (213) 741-8626

SUBJECT REPORT: CABLE-TITE TIE-DOWN SYSTEM TESTING

PREPARED FOR: PRECISION CASTINGS OF TENNESSEE, INC.
430 CALVERT DRIVE
GALLATIN, TN 37066

Date: May 11, 2009

Project No.: 38396-1

Report No.: L-09-830

TABLE OF CONTENTS

1.00 INTRODUCTION

1.1 Purpose

The purpose of the testing was to evaluate the tension strength and load relaxation property of the submitted wall tie-down system (referred to as *Cable-Tite*) in accordance with ICC-ES AC369, *Acceptance Criteria for Steel Assemblies,* effective March 1, 2007.

1.2 Scope of Testing

Our general scope of this testing program included the following:

- Test set-up to accommodate the testing requirement.
- Perform cable strength test on three *Cable-Tite* assemblies in accordance with Section 4.1 of AC369.
- Perform relaxation test and service load test on three *Cable-Tite* assemblies in accordance with Section 4.2 of AC369.
- Preparation of this final report detailing the results, our observation and findings.

2.00 TEST SPECIMEN DESCRIPTION

The *Cable-Tite* tie-down system submitted for testing consisted of one steel wire strand, two cable vises, one anchor nut and locking cap, and one top plate. The submitted drawing and installation instruction are included in Appendix C of this report. All the components were received on March 10, 2009 with a signed affidavit indicating the sample components manufacturing origins (affidavit included in Appendix D). The components listed and described as follows were assembled by Smith-Emery in accordance with the provided instructions to form six test assemblies (three for tensile testing described in Section 3.1 and three for relaxation testing in Section 3.2):

- The anchor nut, locking cap, and top plate were reportedly manufactured by Precision Castings of Tennessee (i.e., Smith-Emery did not sample the components at the manufacturing facility) with a casting trademark of *Cable-Tite* or *CT* as shown in Photo 1 of Appendix B.
- The 7-wire, ¼-inch diameter steel wire strand was reportedly manufactured by Emcocables and reportedly conformed to ASTM A-475 EHS grade. The actual measured wire and strand diameters were 0.0795 inch and 0.248 inch, respectively.
- The ¼-inch cable vises were reportedly manufactured by MacLean Power Systems.

3.00 TEST SETUP AND LOADING PROCEDURE

3.1 Tensile Strength Test

Three cable assemblies were tested for tensile strength in accordance with ASTM A475, *Standard Specification for Zinc-Coated Steel Wire Strand.* The load was applied by a universal testing machine, as shown in Photo 2 of Appendix B. The cable length between the ends of the two vises was approximately 33 inches. The movements between the testing machine crossheads were measured to determine the elongation of the strands. The loading rate was approximately 25 pounds per second.

The following is a list of measuring equipment used for the tensile strength tests:

- A load cell (Omegadyne LCCA-10k) was used to measure the applied loads.
- One displacement transducer (Celesco Model: PT101) were used to measure the elongations.
- A Vishay scanner (Model 5100) for load data monitoring and acquisition.
- A universal testing machine (Tinius Olsen) for load application.

3.2 Relaxation Test

Relaxation tests were conducted on three separate or additional cable assemblies. Each cable assembly was placed in a customized testing frame as shown in Photo 3 in Appendix B and fixed at each end using the PCT fastening hardware. Each test assembly consisted of a 96-inch long wire strand (the length between the cable vises was approximately 89 inches), and one end of the assembly was extended beyond the PCT fastening hardware by using a threaded rod for attachment of a load cell. Before applying the pre-stress load, the nut on the threaded rod at one end of the assembly was hand tightened. For specimen *R1*, the pre-stress load was applied by using a wrench to turn the locking caps, in accordance with the manufacturer's instruction. The measured initial tensile load was 966 pounds. In order to achieve similar initial loads, the loads of the subsequent specimens (*R2* and *R3*) were adjusted by tightening or loosening the nuts at the threaded rod end. The pre-stress loads were applied by client (Andrew Butler) at the time of the initial loading. Once the pre-stress load was reached, it was then periodically monitored and recorded following the schedule prescribed in *Section 4.2.4* of *AC 369* until the load relaxation criteria was met.

The following is a list of measuring equipment used for this relaxation test:

- Three load cells (two *Omegadyne LC101-5k,* and one *Omegadyne LCCA-10k*), one for each test assembly used to measure the applied loads.
- A Vishay scanner (*Model 5100*) for load data monitoring and acquisition.

3.3 Service Load Test

Following completion of the relaxation tests with the load still applied, the same three test assemblies were subjected to a simulated building shrinkage/settlement value of *0.078* inch by loosening the nuts at threaded rod end. The loads at the designated shrinkage/settlement value were recorded as residual tensions.

After determination of the residual tension and while each cable assembly length was still fixed, the assembly was loaded in tension to failure using a center-hole hydraulic ram.

The following is a list of measuring equipment used for this testing program:

- Three load cells (two *Omegadyne LC101-5k,* and one *Omegadyne LCCA-10k*) used to measure the applied loads.
- One LVDT (*Omega LD600-15, s/n. A703-04*) to measure the displacements during shrinkage test.
- A Vishay scanner (*Model 5100*) for load data monitoring and acquisition.
- A hydraulic ram (Enerpac RCH306) for service load test.

4.00 RESULTS AND FINDINGS

4.1 Static Cable Tensile Strength Test

Results of the static tensile tests are summarized in Table 1 below. The load-elongation graphs are included in Appendix A.

Table 1 – Summary of Tensile Strength Test Results

Sample ID	Breaking Strength, P_{ult} (lb)	Elongation (%)	Constructive Stretch, C_s (in/in)	Stretch Modulus, E_s (kip/in/in)	Failure Mode
#1	6,934	4.3	0.0071	275.4	Steel wire fracture near one cable vise.
#2	7,132	4.9	0.0078	277.2	
#3	6,965	4.4	0.0052	280.6	
Average	7,010	4.5	0.0067	277.7	
ASTM A475 Spec. for EHS Grade	*6,650 min.*	*4 min.*	--	--	

Based on the tensile test results above, each cable or wire strand used in the test assembly complied with tensile and elongation requirements of ASTM A475, Extra High Strength Grade.

4.2 Cable Assembly Load Testing

Results of the relaxation and service load tests are summarized in Table 2 below. The graphs of the test data are included in Appendix A. The total time for the relaxation test was 26 days, although for specimen *R1*, it appeared the relaxation was completed in a shorter time. Also, a smaller relaxation factor was observed for specimen *R1*.

Table 21 – Summary of Relaxation Test and Service Load Test Results

Sample ID	Initial Tensile Load, P_{ps} (lb)	Final Tensile Load, P_x (lb)	Relaxation Factor, C_r (%)	Residual Load at *0.078 in.* Shrinkage, P_r (lb)	Elongation at the Maximum Allowable Load [1] (in.)
R1	966	896	7.25%	229	0.404
R2	966	830	14.08%	112	0.502
R3	964	808	16.18%	143	0.516
Average	965	845	12.50%	161	0.474

[1]Since no elongation limit was specified, the maximum allowable load was calculated to be ***3,023*** pounds based on the cable's specified tensile strength of 6,650 lbs. divided by a factor of 2 2 per AC369.

5.00 CONCLUSION AND CLOSURE

5.1 Conclusion

Based on the information and data given and presented in this report, and unless otherwise noted, we make no statement of compliance or noncompliance to any standard or specification for the product tested.

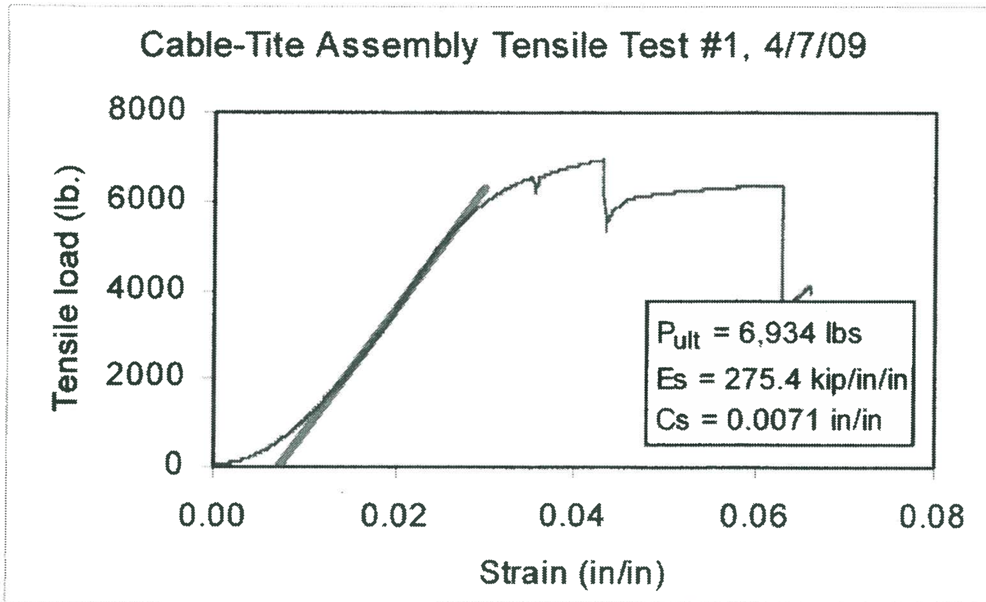
5.2 Closure

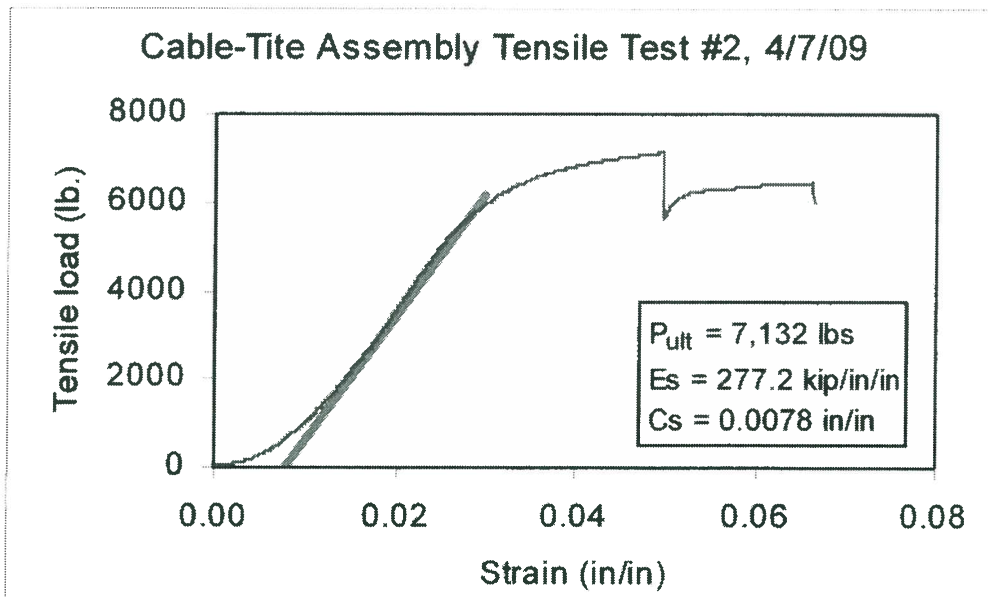
Any findings noted in this report were prepared in accordance with generally accepted material engineering and testing principles and practices. No other warranty, either expressed or implied, is made. This report has been prepared for **Precision Castings of Tennessee, Inc.** to be used for design and/or investigation purposes only. The use of this report for any other purpose shall be at the users' own discretion, based on their own interpretation of the results contained within.

APPENDIX A

DATA GRAPHS

SMITH-EMERY LABORATORIES
An Independent Commercial Testing Laboratory
781 E. Washington Boulevard - 2nd Floor   Los Angeles, California 90021 ◆ (213) 745-5333 ◆ Fax (213) 749-7232





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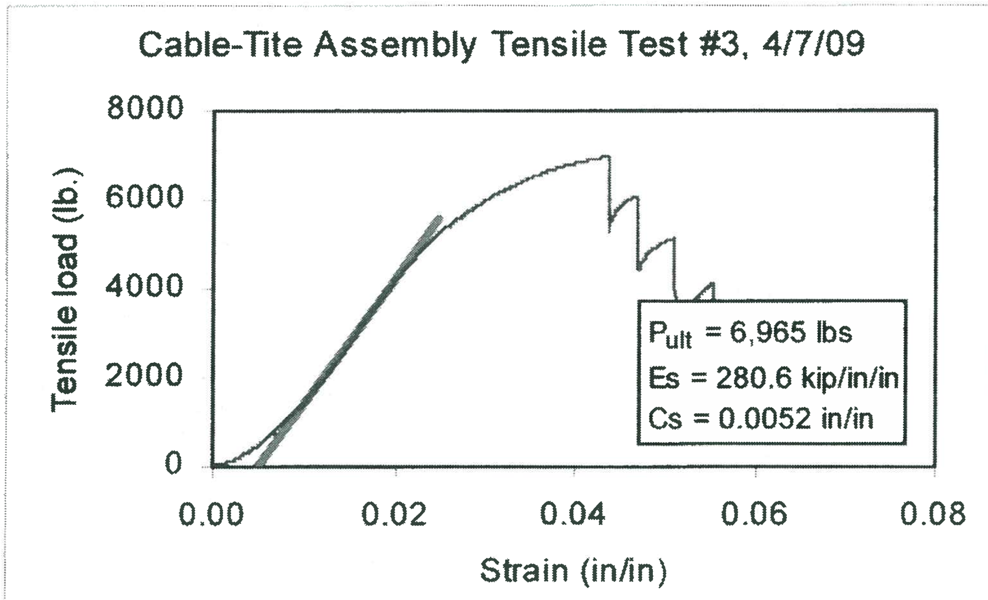
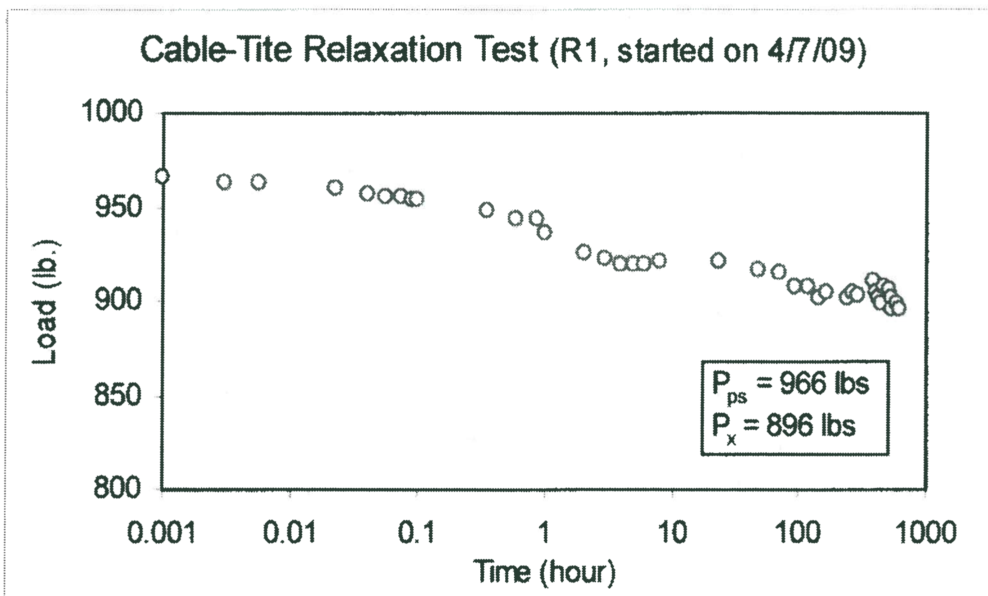
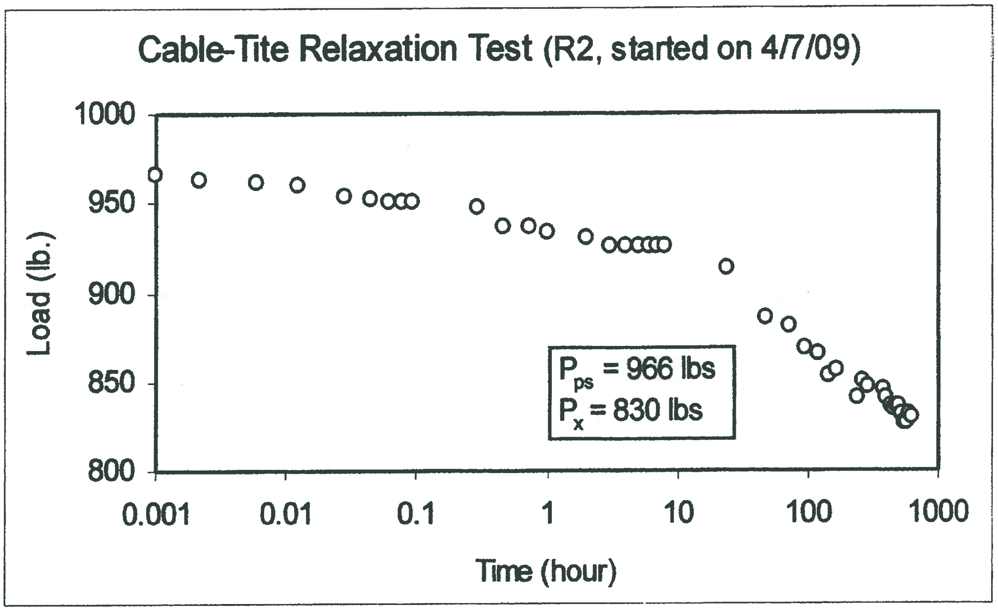
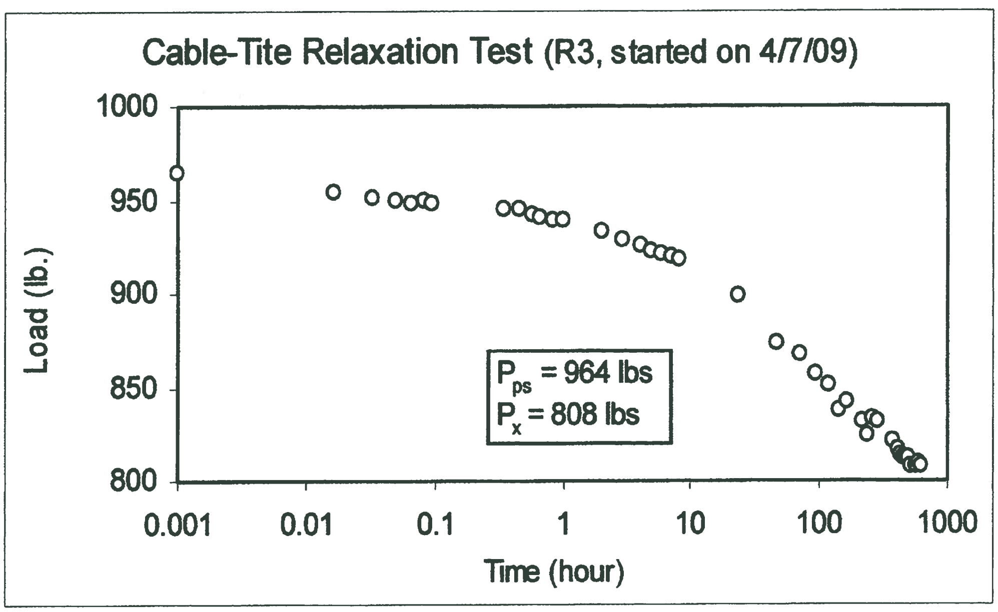




SMITH-EMERY LABORATORIES
An Independent Commercial Testing Laboratory
781 E. Washington Boulevard - 2nd Floor Los Angeles, California 90021 ◆ (213) 745-5333 ◆ Fax (213) 749-7232





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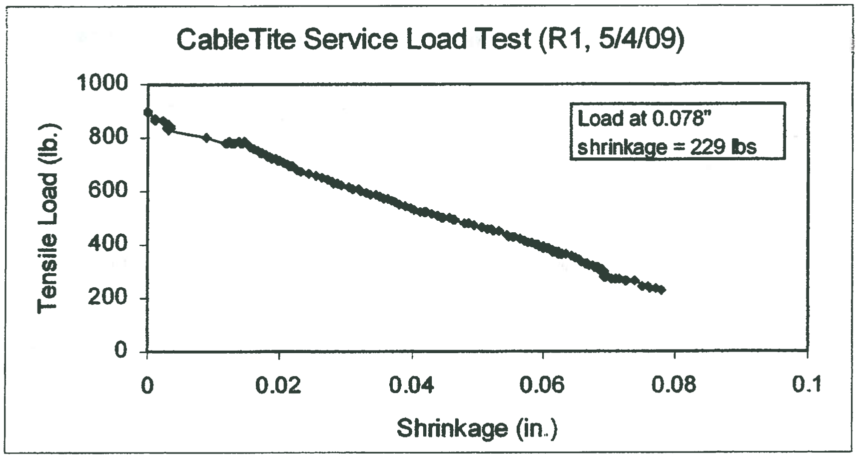

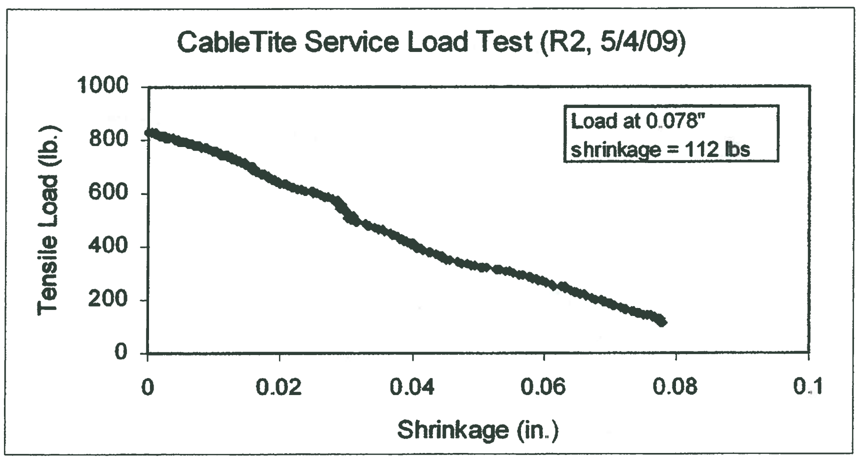

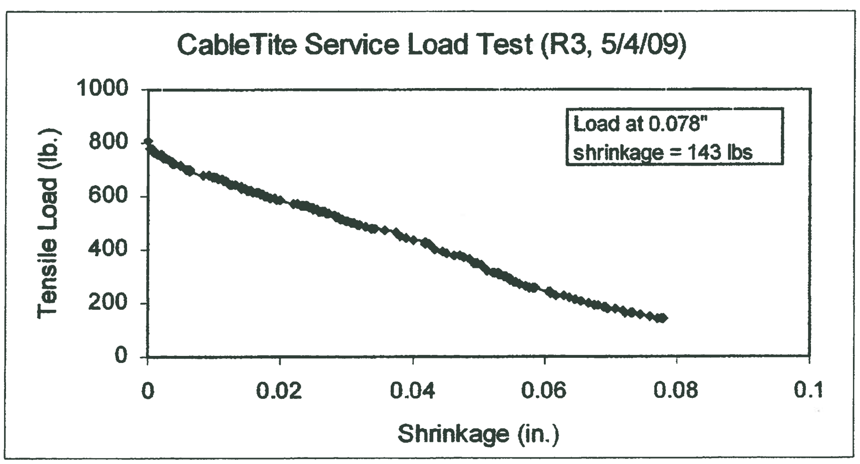

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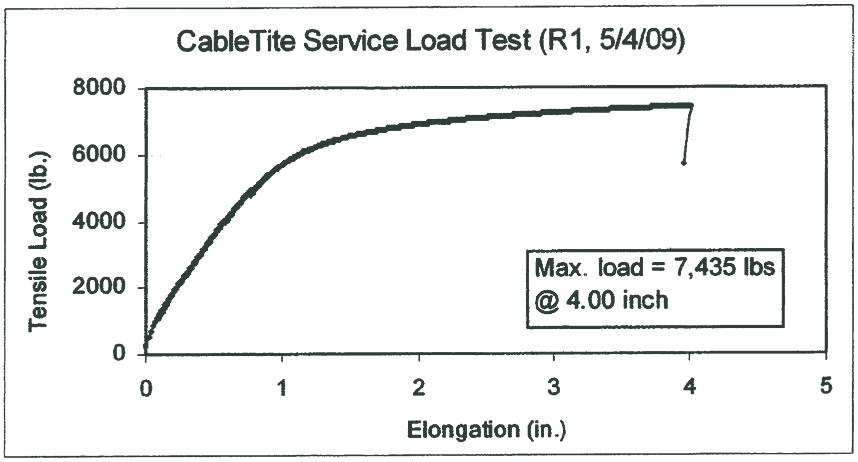

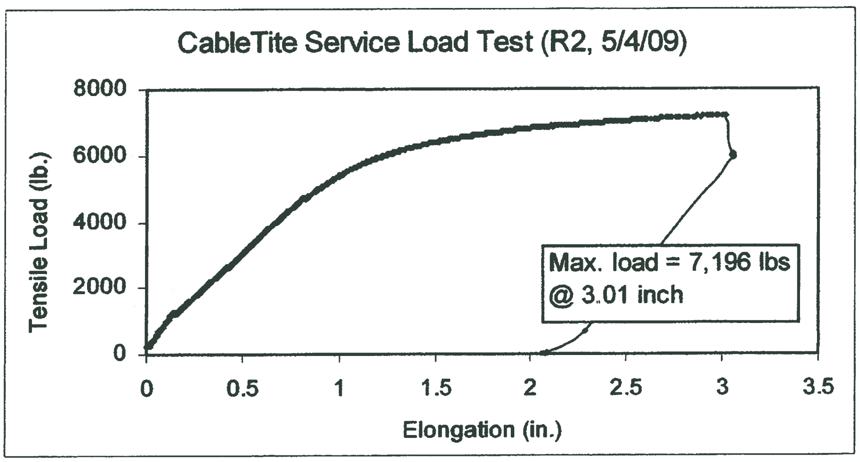

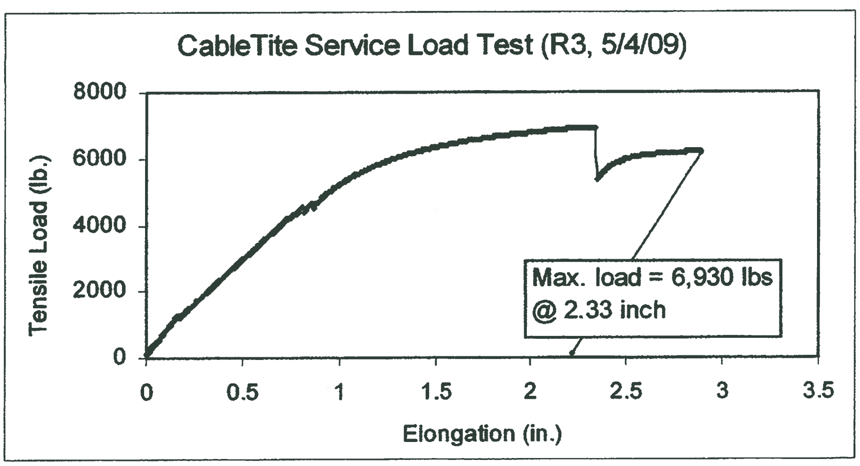

APPENDIX B

TESTING PHOTOS

SMITH-EMERY LABORATORIES
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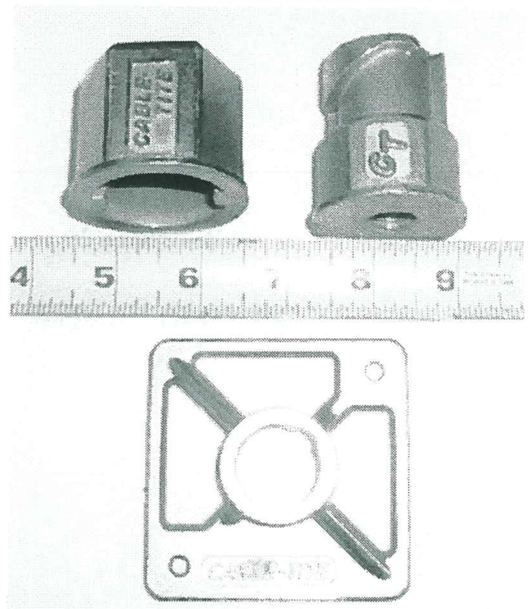

Photo 1 – Cable-Tite: Locking Cap, Anchor Nut, and Top Plate

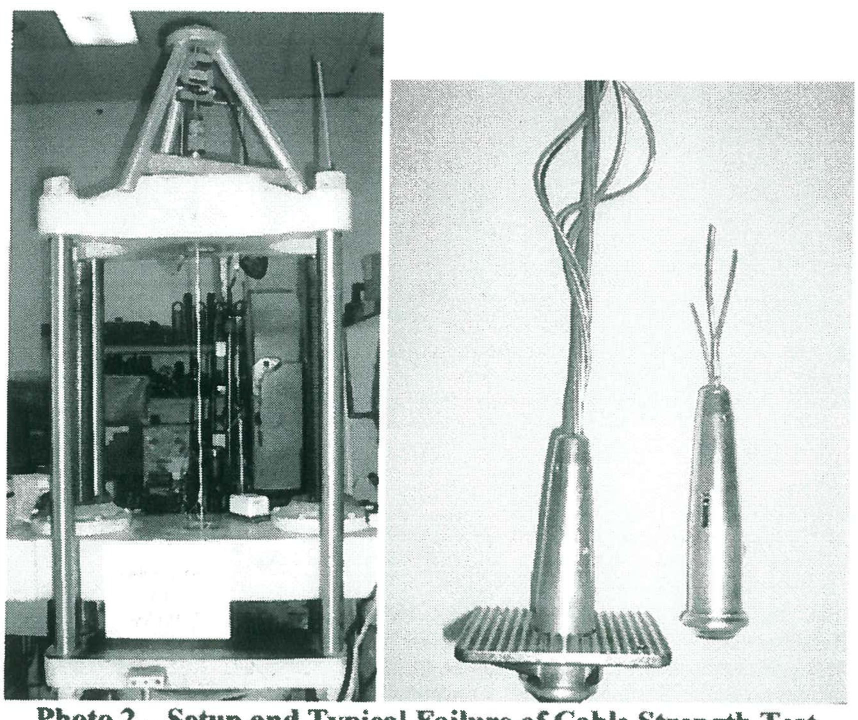

Photo 2 – Setup and Typical Failure of Cable Strength Test

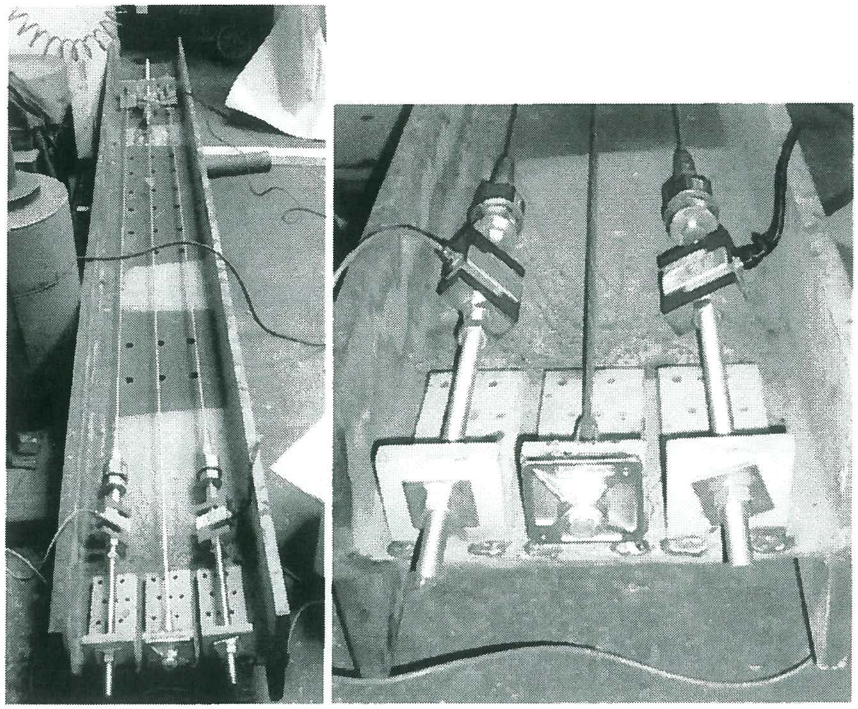

Photo 3 – Setup for Cable Relaxation Test

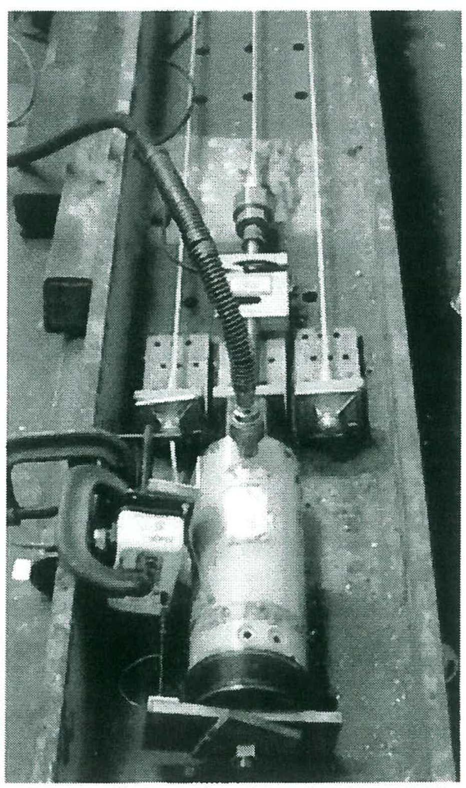

Photo 4 – Setup for Service Load Test

APPENDIX C

PRODUCT DRAWING

REVISIONS				
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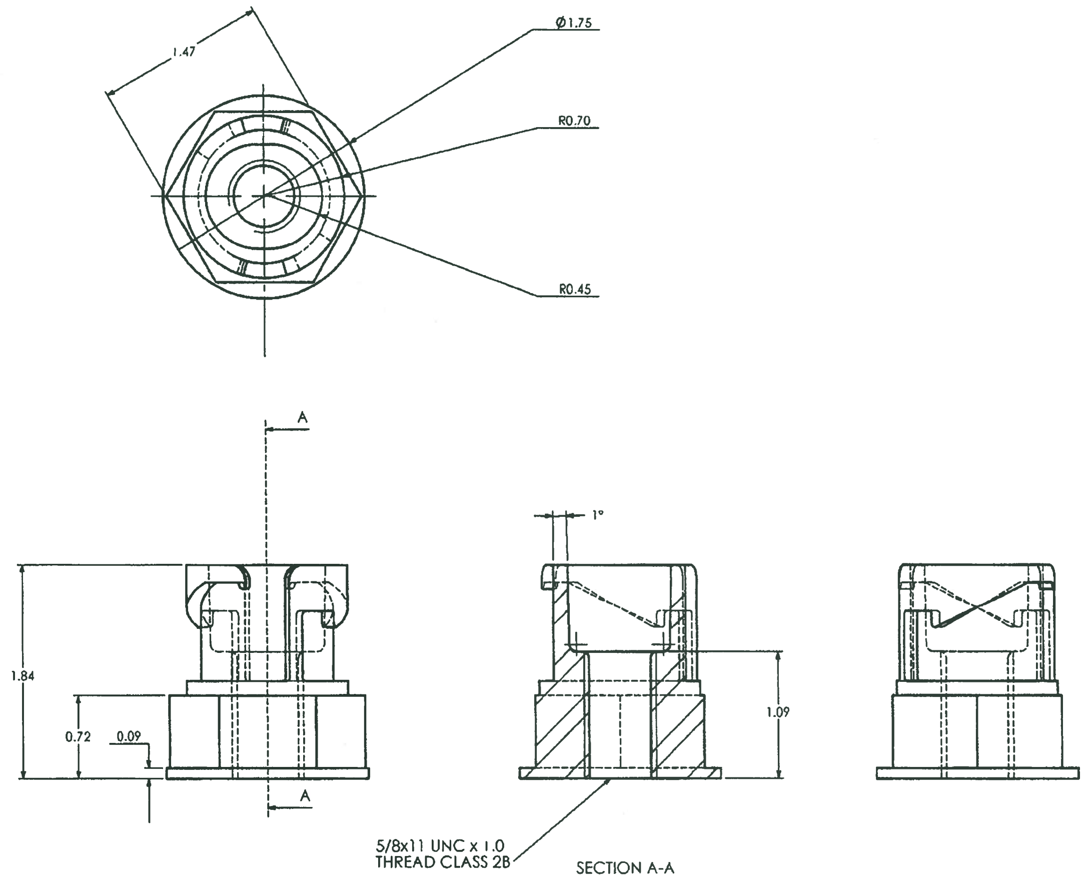

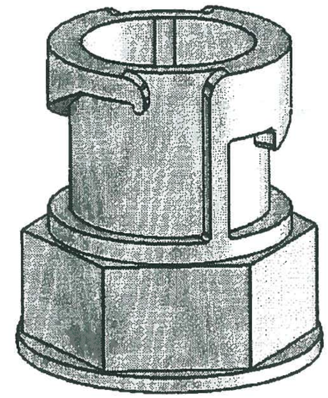

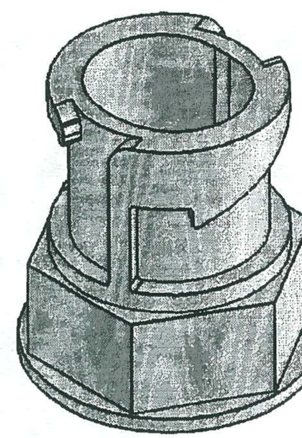

PROPRIETARY AND CONFIDENTIAL

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UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES

TOLERANCES (AS CAST):

FRACTIONAL	± 1/32"
ANGLE	± 0.5°
LINEAR	±0.005" per inch
ALL CORNER RADS	0.003" MIN

	DATE:	NAME.		
DRAWN:	2007.07.12	A BUTLER	CUSTOMER:	CABLE-TITE
CHECKED:			PART NO:	01
ENG APPR:			DESCRIPTION:	ANCHOR
MFG APPR:			MATERIAL:	IC-1020 OR EQUIV.
QA APPR:			FINISH:	125 YELLOW ZINC PLATED
COMMENT:	INVESTMENT CASTING			

CABLE-TITE

DRAWING NO:

CT-C-01-REV 0

WEIGHT: 0.559 LBS

ISSUED: 7/23/2007

REVISIONS				
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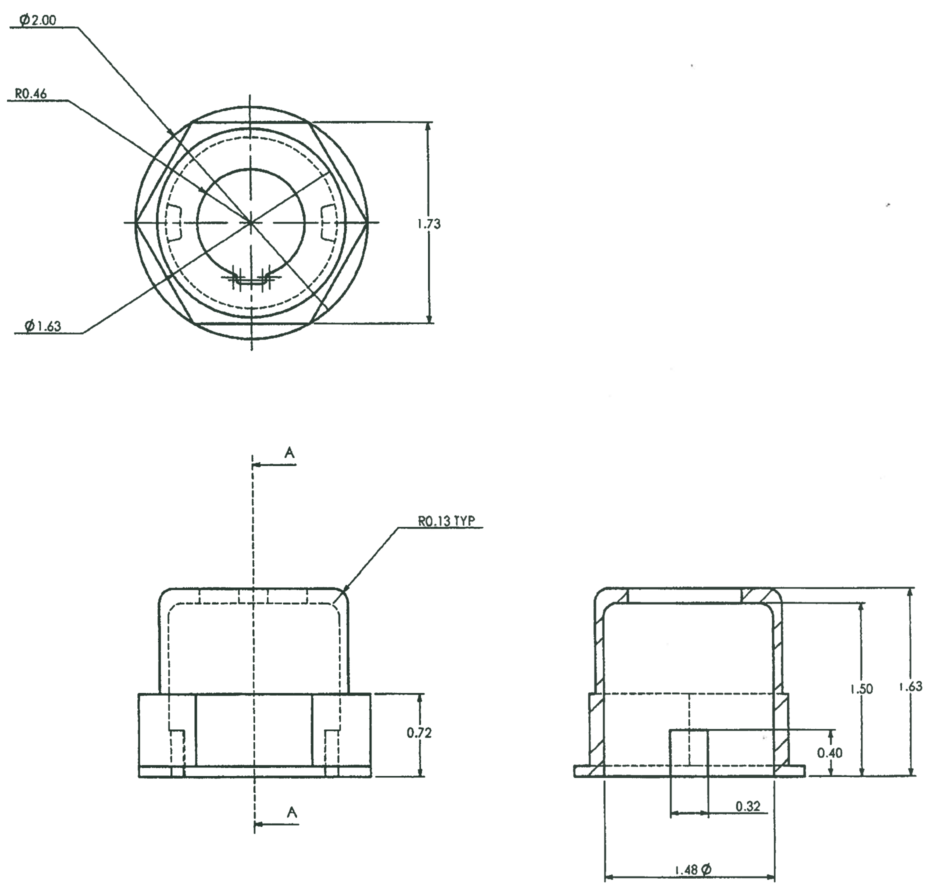
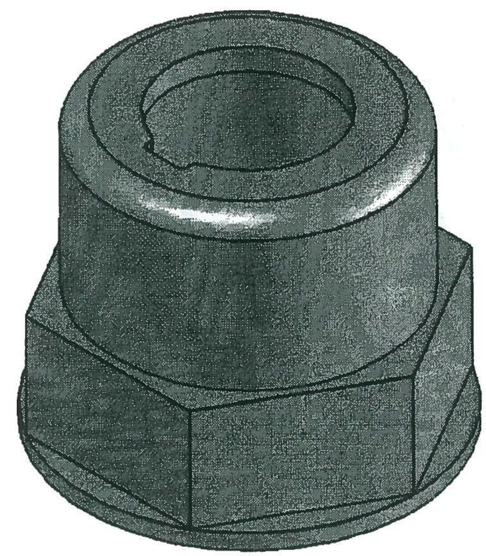


SECTION A-A



PROPRIETARY AND CONFIDENTIAL

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES

TOLERANCES (AS CAST):

FRACTIONAL	± 1/32"
ANGLE	± 0.5°
LINEAR	±0.005" per Inch
ALL CORNER RADS	0.003" MIN

	DATE:	NAME.		
DRAWN:	2007.07.12	A BUTLER	CUSTOMER:	CABLE-TITE
CHECKED:			PART NO:	CT-02
ENG APPR:			DESCRIPTION:	CAP
MFG APPR:			MATERIAL:	IC-1020 OR EQUIV.
QA APPR:			FINISH:	125 YELLOW ZINC PLATED
COMMENT:	INVESTMENT CASTING			

CABLE-TITE

DRAWING NO:

CT-C-02-REV 0

WEIGHT: 0.329 LBS ISSUED: 7/23/2007

REVISIONS				
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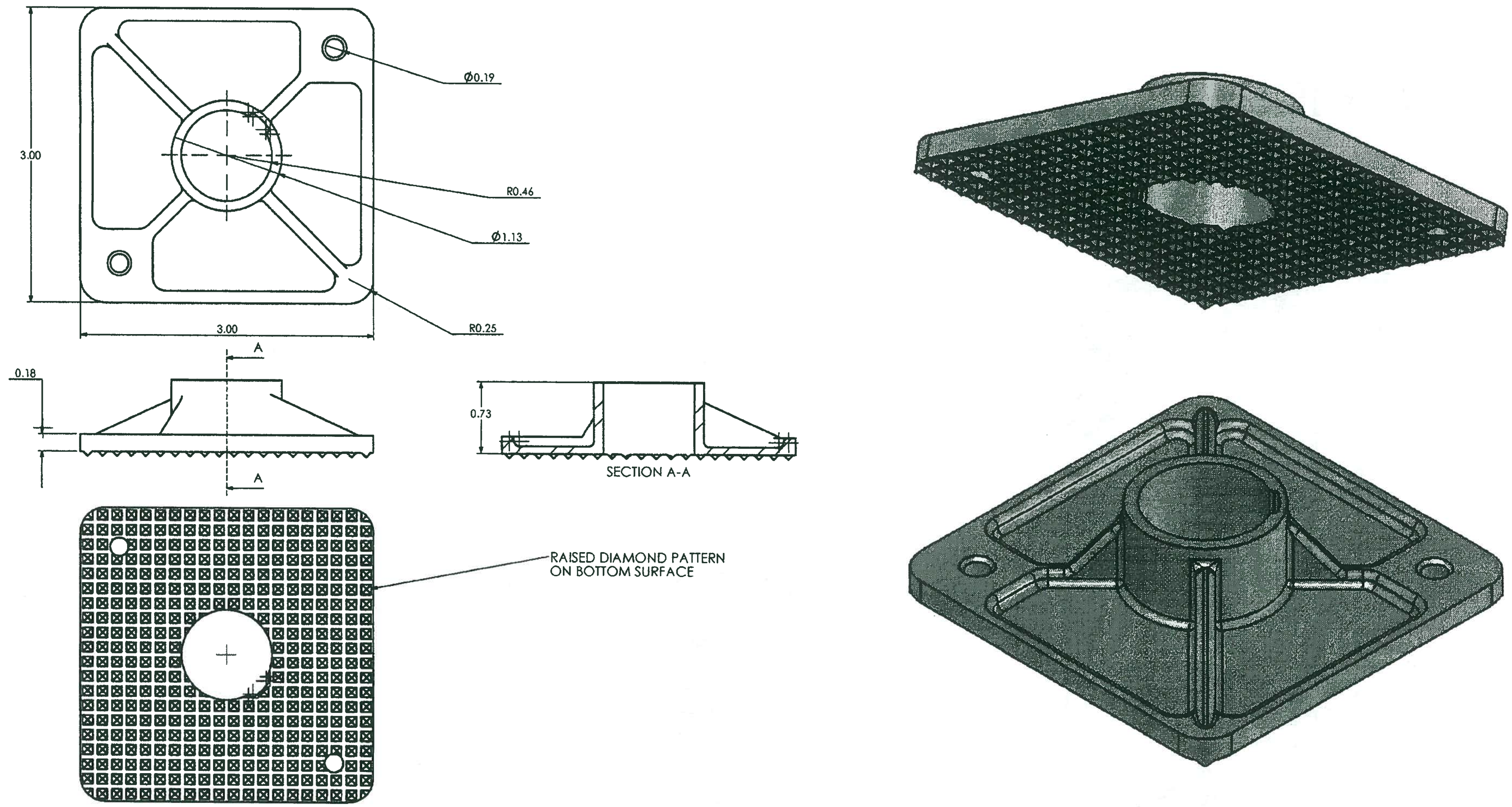


UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES

TOLERANCES (AS CAST):

FRACTIONAL	± 1/32"
ANGLE	± 0.5°
LINEAR	±0.005" per Inch
ALL CORNER RADS	0.003" MIN

	DATE:	NAME:		
DRAWN:	2007.07.12	A BUTLER	CUSTOMER:	PCT
CHECKED:			PART NO:	03
ENG APPR:			DESCRIPTION:	TOP CAP
MFG APPR:			MATERIAL:	IC-1020 OR EQUIV.
QA APPR:			FINISH:	125 YELLOW ZINC PLATED

COMMENT: INVESTMENT CASTING

CABLE-TITE

DRAWING NO:

CT-C-03-REV 0

WEIGHT: 0.348 LBS

ISSUED: 7/23/2007

REVISIONS				
REV.	DESCRIPTION	DATE	DWG NO	APPROVED

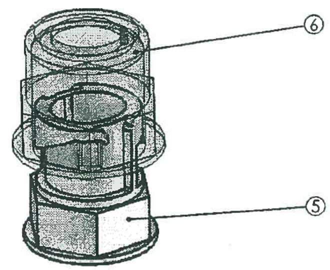
METHOD OF OPERATION

1. J-BOLT (2) IS IMBEDDED IN POURED CONCRETE FOOTING (1)
2. SILL PLATE (3) IS DRILLED SO THAT J-BOLT (2) CAN PASS THROUGH
3. WALL ((4, 10) IS BUILT USING ACCEPTED CONSTRUCTION METHODS
4. AFTER FRAMING IS COMPLETE INSTALLATION OF THE CABLE-TITE SYSTEM BEGINS
5. A HOLE IS DRILLED IN THE TOP HORIZONTAL OF THE WALL (10) TO ALLOW PASSAGE OF TOP CABLE VISE (7A)
6. TOP CABLE VISE (7A) IS FIT INTO TOP PLATE (9) AND ASSEMBLY IS MOUNTED TO TOP OF WALL AND CAN BE SECURED WITH SCREWS OR NAILS IF DESIRED
7. ANCHOR (5) IS SCREWED ONTO J-BOLT (2) AND TIGHTENED WRENCH-TIGHT
8. CABLE (8) IS CUT TO CORRECT LENGTH
9. CABLE IS INSERTED INTO TOP CABLE VISE (7A)
10. LOWER CABLE VISE (7) IS INSERTED INTO CAP (6)
11. CAP (6) IS INSTALLED ON THE ANCHOR (5) IN THE "UNLOCKED POSITION" (SEE PHOTO)
12. WHILE HOLDING THE LOWER CABLE VISE (7) IN ITS EXTREME UPWARD POSITION WITH ONE HAND INSERT THE CABLE (8) INTO THE LOWER CABLE VISE (7) WITH THE OTHER HAND
13. FEED THE CABLE INTO THE LOWER CABLE VISE (7) SO THAT THE CAP (6) REMAINS SNUG AGAINST THE ANCHOR (5) IN THE UNLOCKED POSITION
14. USING THE SUPPLIED WRENCH, TURN THE COLLAR CLOCKWISE THROUGH 120 DEGREES UNTIL A "CLICK" IS HEARD AND FELT. AT THIS POINT THE CABLE (8) IS PROPERLY TENSIONED

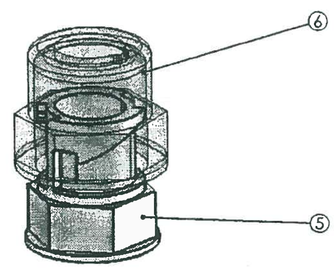
BENEFITS OF THE CABLE-TITE SYSTEM

THE CABLE-TIGHT SYSTEM OFFERS SERVERAL BENEFITS WHEN COMPARED TO COMPETING PRODUCTS.

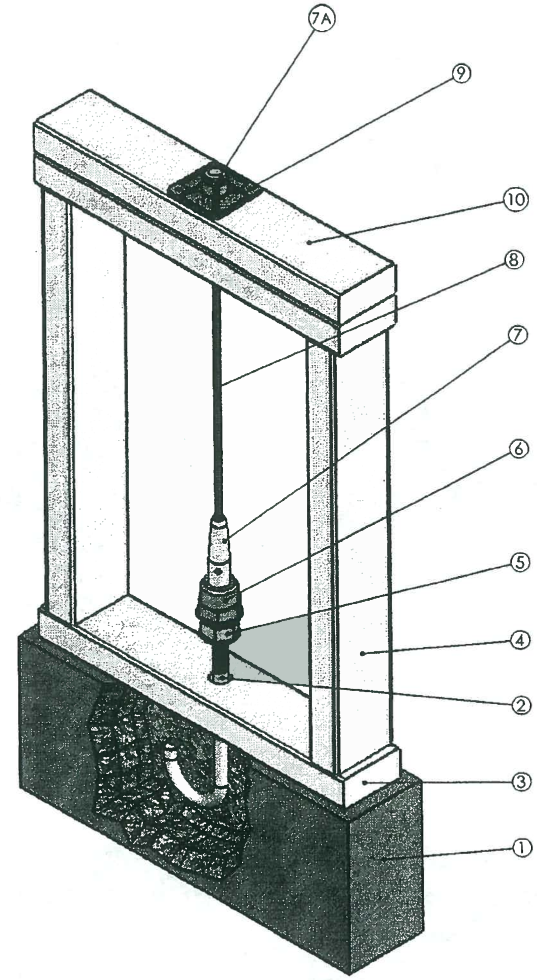
1. MIS-ALIGNMENT COMPENSATION - THE FLEXIBLE NATURE OF THE CABLE CONNECTION ENABLES EASY INSTALLATION EVEN IF THE J-BOLT (2) IS NOT PERPENDICULAR TO THE SILL PLATE OR IF IT IS NOT LINED UP WITH THE TOP CABLE VISE (7).
2. RAPID INSTALLATION - THE CABLE-TITE SYSTEM INSTALLS QUICKLY AS THE CABLE CAN BE CUT PRIOR TO INSTALLATION TO +/- 1" IN LENGTH, AND IS EASILY POSITIONED IN THE TOP CABLE VISE (7). IN THE EVENT OF A POSITIONING ERROR THE CABLE VISE IS EASILY RELEASED SO THE CABLE CAN BE ADJUSTED TO THE CORRECT POSITION.
3. UNIFORM CABLE TENSIONING - THE UNIQUE LOCKING RAMP IN THE CABLE-TITE ANCHOR (5) ENABLES APPLICATION OF UNIFORM TENSION TO EACH CABLE, REGARDLESS OF THE VERTICAL DISTANCE SPANNED



UNLOCKED POSITION



LOCKED POSITION



PROPRIETARY AND CONFIDENTIAL

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES

TOLERANCES (AS CAST):

FRACTIONAL	± 1/32"
ANGLE	± 0.5°
LINEAR	±0.005" per Inch
ALL CORNER RADS	0.003" MIN

	DATE:	NAME:	CUSTOMER:	CABLE-TITE
DRAWN:	2007.07.19	A BUTLER	PART NO:	ASLY
CHECKED:			DESCRIPTION:	ASSEMBLY PRINT
ENG APPR:			MATERIAL:	
MFG APPR:			FINISH:	SEE PART DWGS
QA APPR:				

COMMENT: CABLE-TITE WALL UPLIFT PREVENTION SYSTEM

CABLE-TITE

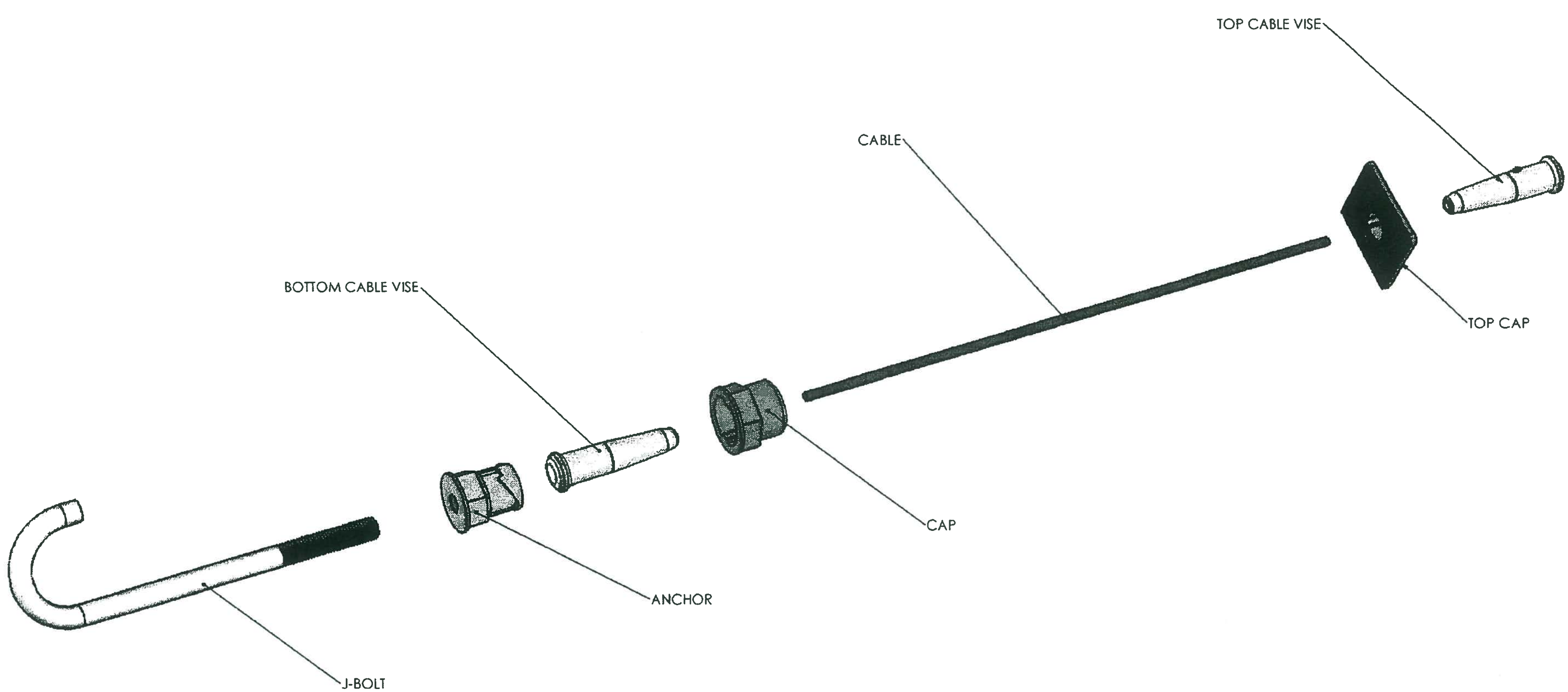
DRAWING NO:

CT-C-04-REV 0

WEIGHT: LBS

ISSUED: 7/23/2007

REVISIONS				
REV.	DESCRIPTION	DATE	DWG NO	APPROVED



PROPRIETARY AND CONFIDENTIAL

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES

TOLERANCES (AS CAST):

FRACTIONAL	± 1/32"
ANGLE	± 0.5°
LINEAR	±0.005" per Inch
ALL CORNER RADS	0.003" MIN

	DATE:	NAME:		
DRAWN:	2007.07.23	A BUTLER	CUSTOMER:	CABLE-TITE
CHECKED:			PART NO:	ASLY
ENG APPR:			DESCRIPTION:	EXPLODED VIEW
MFG APPR:			MATERIAL:	
QA APPR:			FINISH:	SEE PART DWGS

COMMENT: EXPLODED VIEW OF CABLE-TITE ASSEMBLY

CABLE-TITE

DRAWING NO:

CT-C-05-REV 0

WEIGHT: LBS

ISSUED: 7/23/2007

SMITH-EMERY LABORATORIES
An Independent Commercial Testing Laboratory
781 E. Washington Boulevard - 2nd Floor Los Angeles, California 90021 ◆ (213) 745-5333 ◆ Fax (213) 749-7232

APPENDIX D

SIGNED AFFIDAVIT ON PRODUCT SAMPLING

CABLE-TITE
SECURE HOME TIE-DOWN SYSTEMS

March 6, 2009

Dear Sirs,

Representative samples are enclosed for your testing. These anchor nuts, locking caps, and top plates enclosed were manufactured at our facility in Gallatin Tennessee and are representative samples from what has been manufactured in the past. These samples are the same as will be manufactured in the future.

The cable vises were manufactured by MacLean Power, 11411 West Addison Street, Franklin Park, Illinois 60131. These samples are representative of the shipment we received from them, and represent the quality they will continue to manufacture in the future.

The cable strand length was sampled from a roll of cable supplied by Utilicor, Nashville, TN and it was manufactured by Emcocables. It is a representative sample from what they supplied us and is representative of what we will continue to purchase from them, and recommend for correct installation of the Cable-Tite system.

Best Regards,

Andrew Butler,
Director of Technical Services

Sonja Jean Burton
Notary Public
My commission expires: 10-12-2010

SONJA JEAN BURTON
STATE OF TENNESSEE NOTARY PUBLIC
SUMNER COUNTY

Designation: F 1554 – 07a

Standard Specification for Anchor Bolts, Steel, 36, 55, and 105-ksi Yield Strength[1]

This standard is issued under the fixed designation F 1554; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This specification covers straight and bent, headed and headless, carbon, carbon boron, alloy, or high-strength low-alloy steel anchor bolts (also known as anchor rods). The anchor bolts are furnished in three strength grades, two thread classes, and in the sizes specified in Section 4.

1.2 The anchor bolts are intended for anchoring structural supports to concrete foundations. Such structural supports include building columns, column supports for highway signs, street lighting and traffic signals, steel bearing plates, and similar applications.

1.3 Supplementary requirements are included to provide for Grade 55 weldable steel, permanent manufacturers and grade identification, and impact properties for Grades 55 and 105.

1.4 Zinc coating requirements are included in Section 7 for applications requiring corrosion protection.

1.5 The recommended grade and style of nut and washer are included in 6.6 and 6.7 for each grade.

1.6 This specification does not cover the requirements for mechanical expansion anchors, powder-activated nails or studs, or anchor bolts fabricated from deformed bar.

1.7 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information only.

2. Referenced Documents

2.1 *ASTM Standards:* [2]

A 194/A 194M Specification for Carbon and Alloy Steel Nuts for Bolts for High Pressure or High Temperature Service, or Both

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products

A 563 Specification for Carbons and Alloy Steel Nuts

A 673/A 673M Specification for Sampling Procedure for Impact Testing of Structural Steel

A 751 Test Methods, Practices, and Terminology for Chemical Analysis of Steel Products

B 695 Specification for Coatings of Zinc Mechanically Deposited on Iron and Steel

D 3951 Practice for Commercial Packaging

F 436 Specification for Hardened Steel Washers

F 606 Test Methods for Determining the Mechanical Properties of Externally and Internally Threaded Fasteners, Washers, Direct Tension Indicators, and Rivets

F 2329 Specification for Zinc Coating, Hot-Dip, Requirements for Application to Carbon and Alloy Steel Bolts, Screws, Washers, Nuts, and Special Threaded Fasteners

2.2 *Research Council on Structural Connections Standard:*[3]

Specification for Structural Joints Using ASTM A 325 or A 490 Bolts

2.3 *ASME Standards:*[4]

B 1.1 Unified Screw Threads

B 1.3 Screw Thread Gaging Systems for Dimensional Acceptability

B 18.2.2 Square and Hex Nuts

B 18.18.2M Inspection and Quality Assurance for High Volume Machine Assembly Fasteners

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *anchor bolt*—steel rod or bar, one end of which is intended to be cast in concrete, while the opposite end is threaded and projects from the concrete, for anchoring other material to the concrete. The end cast in concrete may be either straight or provided with an anchor such as a bent hook, forged head, or a tapped or welded attachment to resist forces imposed on the anchor bolt, as required.

3.1.2 *manufacturer*—manufacturer of the anchor bolt; the party that performs the cutting, bending, and threading operations.

3.1.3 *producer*—manufacturer of the steel rods or bars.

3.1.4 *purchaser*—purchaser of the finished anchor bolt, or his designated agent.

[1] This specification is under the jurisdiction of ASTM Committee F16 on Fasteners and is the direct responsibility of Subcommittee F16.02 on Steel Bolts, Nuts, Rivets and Washers.

Current edition approved Dec. 1, 2007. Published January 2008. Originally approved in 1994. Last previous edition approved in 2007 as F 1554 – 07.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from Research Council on Structural Connections, c/o Industrial Fasteners Institute, 1717 East 9th Street, Cleveland, OH 44114.

[4] Available from American Society of Mechanical Engineers (ASME), ASME International Headquarters, Three Park Ave., New York, NY 10016-5990, http://www.asme.org.

***A Summary of Changes section appears at the end of this standard.**

3.1.5 *responsible party*—see Section 18; this may be the manufacturer or supplier.

3.1.6 *supplier*—agent who furnishes the finished anchor bolt and nuts to the purchaser; this may be the manufacturer.

4. Classification

4.1 The anchor bolts are furnished in three grades denoting minimum yield strength and two classes denoting thread class as follows:

Grade	Description		
	Tensile Strength, ksi (MPa)	Yield Strength, min, ksi (MPa)	Size Range, in. (mm)
36[A]	58–80 (400–558)	36 (248)	¼ –4 (6.4–102)
55	75–95 (517–655)	55 (380)	¼ –4 (6.4–102)
105	125–150 (862–1034)	105 (724)	¼ –3 (6.4–76)
Class			
1A	anchor bolts with Class 1A threads		
2A	anchor bolts with Class 2A threads		

[A] When Grade 36 is specified, a weldable Grade 55 may be furnished at the supplier's option.

4.2 Weldable steel for Grade 55 is provided for in Supplementary Requirement SI.

5. Ordering Information

5.1 Orders for anchor bolts should include the following information:

5.1.1 *Quantity (Number of Pieces)*—If the purchaser intends to perform destructive tests on finished anchor bolts, the manufacturer should be advised so that an adequate number are produced, especially for the sizes and types not readily available from stock.

5.1.2 Name of product (steel anchor bolt).

5.1.3 ASTM designation and year of issue.

5.1.4 Grade and class, that is, Grade 36, 55, or 105 and Class 1A or 2A. Weldable Grade 55 may be furnished when Grade 36 is ordered (see 4.1).

5.1.5 Copper, if copper bearing steel is required.

5.1.6 *Size and Dimensions*—Include the diameter and threads (based on nominal thread diameter), bolt length, thread length, and length of hook if a hook is required, or provide a drawing showing the required information.

5.1.7 Zinc coatings in accordance with 7.1. When zinc coatings in accordance with 7.1 are required, specify the zinc coating process to be used, that is, hot dip, mechanically deposited, or no preference (see 7.1). Also, specify the length to be coated as measured from the exposed end.

5.1.8 *Other Coatings*—Specify other protective coatings, if required (see 7.2).

5.1.9 Number of nuts, either the total number or number per bolt.

5.1.10 Number of washers, either the total number or number per bolt, and dimensions if other than standard.

5.1.11 Inspection at place of manufacture, if required (see 15.1).

5.1.12 Color coding, if different from the standard in 19.1.

5.1.13 Test reports, if required (see 17.1).

5.1.14 Supplementary requirements, if required.

5.1.15 Special requirements, if required.

NOTE 1—An example of a typical order follows: 5000 pieces; steel anchor bolts; ASTM designations including issue date; Grade 55; Class 2A; Supplementary Requirement S 1; 1.0-8-in. thread size by 15-in. long, 3.0-in. thread length, 4.0-in. hook; zinc coated by hot dipping 5.0 in. from exposed end; each with one zinc-coated nut and washer; test report required.

6. Materials and Manufacture

6.1 *Process*—Steel for anchor bolts shall be made by the open-hearth, basic-oxygen, or electric-furnace process.

6.2 *Threading*—Threads shall be rolled, cut, or ground at the option of the manufacturer, unless otherwise specified.

6.3 *Heat Treatment*:

6.3.1 When required, the anchor bolts may be heat treated to develop the specified properties. Heat treatment shall be at the option of the manufacturer.

6.3.2 Heat treatment may be performed prior to or after bending or threading.

6.3.3 When heat treatment is required, the anchor bolts shall be heat treated by quenching in a liquid medium from above the transformation temperature and then tempering by reheating to a temperature not less than 800°F (425°C) for Grade 55 and 1100°F (593°C) for Grade 105.

6.4 *Bending*:

6.4.1 When required, hooks, shall be made by cold bending or hot bending. The bent portion shall be free from cracks when examined at 10× magnification after bending.

6.4.2 Hot bending performed on bar stock without heat treatment shall not have the temperature exceed 1300°F (705°C) at any location during hot bending and shall be allowed to air cool after bending.

6.4.3 Hot bending performed on heat-treated bar stock shall not have the temperature come within 100°F (56°C) of the tempering (stress relieve) temperature of the heat-treat process at any location during hot bending and shall be allowed to air cool after bending.

6.4.4 The bending shall not reduce the cross-sectional area below that required in 10.3.

6.5 *Secondary Processing*—If a subcontractor, or party other than the manufacturer or producer, performs heat treatment, coating, welding, machining, or other process affecting the properties or performance of the anchor bolts, the anchor bolts shall be inspected and tested after such processing by the party responsible for supplying the anchor bolts to the purchaser.

6.6 *Recommended Nuts*:

6.6.1 Unless otherwise specified, all nuts used on these anchor bolts shall conform to the requirements of Specifications A 194/A 194M or A 563 and shall be of the grade, surface finish, and style for each grade and size of anchor bolt as follows:

Anchor Bolt Grade and Size, in. (mm)		Specification A 563 Recommended Nut			
		Plain		Hot-Dip or Mechanical Zinc Coated in accordance with 7.1	
Grade	Size, in. (mm)	Grade	Style	Grade	Style
36	¼ –1½ (6.4–38)	A	Hex	A	Hex
	over 1½ –4.0 (38–102)	A	Heavy Hex	A	Hvy Hex
55	¼ –1½ (6.4–38)	A	Hex	A	Hvy Hex
	over 1½ –4.0 (38–102)	A	Heavy Hex	A	Hvy Hex
105	¼ –1½ (6.4–38)	D	Hex	DH	Hvy Hex
	over 1½ –3.0 (38–76)	DH	Heavy Hex	DH	Hvy Hex

6.6.2 The requirements for the recommended grade and style of nut may be fulfilled by furnishing a nut of one of the grades or styles listed in Specifications A 194/A 194M or A 563 having a proof load stress equal to or higher than the minimum tensile strength specified for the anchor bolt.

6.7 *Recommended Washers*:

6.7.1 The washer material and dimensions shall be specified in the inquiry and the order (see Note 2).

6.7.2 Unless the requirement of 6.7.1 is met, washers conforming to the requirements of Specification F 436, Type 1 shall be furnished.

6.7.3 When anchor bolts are specified to be zinc coated, the washers shall be zinc coated as specified in 7.1, except that the coating process for the washers need not be the same as that for the anchor bolts and nuts.

NOTE 2—Washers used on anchor bolts, installed in holes with dimensions greater than oversize or short slot as defined by the Research Council on Structural Connections, require design consideration. (For guidance refer to Specification for Structural Joints Using ASTM A 325 or A 490 Bolts.)

7. Protective Coatings

7.1 *Zinc, Hot Dip or Mechanically Deposited*—Specification F 2329, and mechanically deposited, Specification B 695, Class 55.

7.1.1 When zinc-coated anchor bolts with the coating specified in 7.1 are required, the purchaser shall specify the zinc coating process, for example, hot dip, mechanically deposited, or no preference.

7.1.2 When hot-dip is specified, the fasteners shall be zinc coated by the hot-dip process in accordance with the requirements of Specification F 2329 .

7.1.3 When mechanically deposited is specified, the fasteners shall be zinc coated by the mechanical deposition process in accordance with the requirements of Class 55 of Specification B 695.

7.1.4 When no preference is specified, the supplier may furnish either a hot-dip zinc coating in accordance with Specification F 2329 , or a mechanically deposited zinc coating in accordance with Specification B 695, Class 55. Threaded components (bolts and nuts) shall be coated by the same zinc-coating process, and the supplier's option is limited to one process per item, with no mixed processes in a lot.

7.2 *Other Coatings*:

7.2.1 Coatings other than the zinc coatings specified in 7.1 shall be as specified by the purchaser on the purchase order.

7.2.2 The complete specification shall be included as part of the purchase order when other coatings are specified.

8. Chemical Composition

8.1 Anchor bolts shall have a chemical composition conforming to the requirements listed in Table 1 for Grade 36 and Table 2 for Grades 55 and 105.

8.2 Grade 55 ordered as weldable shall conform to the requirements specified in Supplementary Requirement S1.

8.3 Anchor bolts made from low-carbon martensitic steel shall not be permitted.

8.4 The application of heats of steel to which bismuth, selenium, tellurium, or lead has been added intentionally shall not be permitted.

8.5 Product analyses may be made by the purchaser from finished anchor bolts representing each heat. The chemical composition thus determined shall conform to the requirements specified in 8.1 through 8.4.

9. Mechanical Properties

9.1 *Bars*—The bars or rods from which the anchor bolts are made shall conform to the tensile properties listed in Table 3, except when heat treated after bending or threading.

9.2 *Anchor Bolts*—The finished anchor bolts shall conform to the tensile properties listed in Table 3 for tests on machined specimens and Table 4 for axial tests on full-size threaded anchor bolts.

10. Anchor Bolt Dimensions

10.1 *Nominal Size*—The nominal anchor bolt diameter shall be the same as the nominal thread diameter.

10.2 *Body Diameter*:

10.2.1 When threads are rolled, the body diameter shall not be less than the minimum pitch diameter for the thread class, 1A or 2A, designated by the purchaser and specified in ANSI/ASME B 1.1. Class 2A shall be furnished when the thread class is not specified.

10.2.2 The body diameter shall not be less than the minimum major diameter when threads are cut.

10.2.3 The minimum body diameters are listed in Table 5 based on the requirements specified in 10.2.1 and 10.2.2.

TABLE 1 Chemical Requirements for Grade 36

Element	Diameter, in. (mm)		
	To ¾ (20), incl	Over ¾ to 1½ (20 to 40), incl	Over 1½ to 4 (40 to 100), incl
Carbon, max, %			
Heat	0.26	0.27	0.28
Product	0.29	0.30	0.31
Manganese, %			
Heat	[A]	0.60–0.90	0.60–0.90
Product	[A]	0.54–0.98	0.54–0.98
Phosphorus, max, %			
Heat	0.04	0.04	0.04
Product	0.05	0.05	0.05
Sulfur, max, %			
Heat	0.05	0.05	0.05
Product	0.06	0.06	0.06
Copper, min, % (when specified)			
Heat	0.20	0.20	0.20
Product	0.18	0.18	0.18

[A] Optional with the manufacturer but shall be compatible with weldable steel.

TABLE 2 Chemical Requirements for Grades 55 and 105

Element	Composition, %	
	Heat Analysis	Product Analysis
Phosphorous, max	0.040	0.048
Sulfur, max	0.050	0.058
Copper, min (when Cu is specified)	0.20	0.18

TABLE 3 Tensile Properties for Bars and Machined Specimens

	Grade		
	36	55	105
Tensile strength, ksi	58–80	75–95	125–150
Tensile strength, MPa	(400–552)	(517–655)	(862–1034)
Yield strength, min, ksi (0.2 % offset)	36	55	105
Yield strength, min, MPa (0.2 % offset)	248	380	724
Elongation in 8 in. (200 mm), min, %[A]	20	18	12
Elongation in 2 in. (50 mm), min, %[A]	23	21	15
Reduction of Area, min, %			
¼ to 2 in. (6.4 to 50 mm), incl	40	30	45
over 2 to 2½ in. (50 to 63 mm), incl	40	22	–45
over 2½ to 3 in. (63 to 76), incl	40	20	45
over 3 to 4 in. (76 to 102 mm), incl	40	18	. . .

[A] Elongation in 8 in. (200 mm) applies to bars. Elongation in 2 in. (50 mm) applies to tests on machined specimens.

10.3 *Bend Section*—The bend section of bent anchor bolts shall have a cross-sectional area not less than 90 % of the area of straight portions. The area in the bend shall be calculated by the following formula: $A_b = 0.25\pi D \cdot d$

where

A_b = cross-sectional area in the bend,
d = minor (or minimum) diameter at any point, generally in the plane of the bend, and
D = major diameter, at the same cross section as, and at 90 degrees to, the minor diameter.

10.4 *Length*:

10.4.1 The overall length of straight anchor bolts, or length to the inside of the hook, shall be the specified length ±½ in. (13 mm) for lengths 24 in. (600 mm) or less, and ±1 in. (25 mm) for longer bolts (see Fig. 1).

10.4.2 The length of hooks shall be the specified length, ±10 % of the specified hook length, or ±½ in. (13 mm), whichever is greater.

10.5 *Bend Angle*—The bend angle of hooks shall not vary from that specified by more than ±5°.

10.6 *Coated Length*—When only the exposed end of the anchor bolt is required to be zinc coated, the length of zinc coating shall not be less than that specified on the order.

10.7 *Other Dimensions*:

10.7.1 Tolerances for dimensions other than those given in 10.1 through 10.6 shall be as specified by the purchaser.

10.7.2 When tolerances are not specified, they shall be in accordance with the manufacturer's documented standard practice.

11. Thread Dimensions

11.1 *Uncoated Anchor Bolts*:

11.1.1 Unless otherwise specified, uncoated threads shall be Unified Coarse Thread Series as specified in the latest issue of ANSI/ASME B 1.1, and they shall have Class 1A or 2A tolerances, as specified by the purchaser. Class 2A shall be furnished when the class is not specified.

11.1.2 When required, anchor bolts having a nominal diameter greater than 1.0 in. (25.5 mm) may be specified to have threads conforming to the 8-Thread Series (8 UN Series) in ANSI/ASME B 1.1, and they shall have Class 2A tolerances.

11.2 *Anchor Bolts Zinc Coated in Accordance With 7.1, Specification F 2329, and Specification B 695, Class 55*:

11.2.1 Unless otherwise specified, anchor bolts hot dip or mechanically zinc coated in accordance with 7.1.1 through 7.1.4 (requiring overtapped nuts, see Note 3) shall be the Unified Coarse Thread Series and shall have Class 1A or 2A threads, as specified by the purchaser, before zinc coating. After zinc coating, and due to the zinc buildup, the pitch and major diameters for hot-dip zinc-coated anchor bolts shall not exceed the dimensions listed in Table 6.

NOTE 3—Zinc-coated nuts of the grade and style recommended in 6.6.1, when overtapped the diametral allowance for the thread series listed in the table entitled "Thread Dimensions and Overtapping Allowances for Nuts" in Specification A 563, will develop the bolt tensile strength required in Table 4 of this specification.

11.2.2 Thread conformance shall be verified during manufacture. In case of dispute, a calibrated thread ring gage of the same size as the oversize limit specified in 11.2.1 (Class X tolerance, gage tolerance plus) shall be used to verify compliance. Assembly of the gage shall be possible with hand effort, following the application of light machine oil to prevent galling and damage to the gage.

11.3 *Thread Length*—The thread length shall not vary from that specified more than +1.0 in. (25.5 mm), –0.00 in. (0.00 mm).

11.4 *Thread Gaging System*—Thread acceptability shall be in accordance with System 21 or ANSI/ASME B 1.3, unless otherwise specified.

12. Workmanship

12.1 Anchor bolts shall be commercially smooth and free of burrs, laps, seams, cracks, and other injurious manufacturing defects that would make them unsuitable for the intended application.

13. Number of Tests and Retests

13.1 *Testing Responsibility*:

13.1.1 The anchor bolt manufacturer or supplier, whichever is the responsible party as defined in Section 18, shall be responsible for conducting or ensuring that the required tests have been conducted to determine compliance with all of the requirements of this specification and the purchaser order.

13.1.2 Reports of tension tests, conducted by the steel producer on bar stock used to manufacture the anchor bolts without additional heat treatment, may be used to qualify the finished anchor bolt tensile properties.

13.1.3 The purchaser shall be permitted to perform any of the tests and inspections listed in this specification or the purchaser order.

13.2 *Lot Definition*:

13.2.1 *Bar Stock Tensile Tests*—For tensile tests conducted by the steel producer on bars to be used for the manufacture of

TABLE 4 Axial Tensile Properties for Full-Size Anchor Bolts

Nominal Size, in.	Threads/ in.	Stress Area,[A] in.^{2}	Anchor Bolt Grade 36: Tensile Strength,[B] klbf	36: Yield Strength,[BC] min, klbf	55: Tensile Strength,[B] klbf	55: Yield Strength,[BC] min, klbf	105: Tensile Strength,[B] klbf	105: Yield Strength,[BC] min, klbf
Unified Coarse Thread Series (UNC)								
¼	20 UNC	0.0318	1.89–2.54	1.15	2.4–3.0	1.75	3.98–4.27	3.34
⅜	16 UNC	0.0775	4.5–6.2	2.8	5.8–7.36	4.26	9.7–11.6	8.14
½	13 UNC	0.1419	8.2–11.4	5.1	10.6–13.5	7.8	17.7–21.3	14.9
⅝	11 UNC	0.226	13.1–18.1	8.1	17.0–21.5	12.4	28.2–33.9	23.7
¾	10 UNC	0.334	19.4–26.7	12.0	25.0–31.7	18.4	41.8–50.1	35.1
⅞	9 UNC	0.462	26.8–37.0	16.6	34.6–43.9	25.4	57.8–69.3	48.5
1	8 UNC	0.606	35.2–48.5	21.8	45.4–57.6	33.3	75.8–90.9	63.6
1⅛	7 UNC	0.763	44.3–61.0	27.5	57.2–72.5	42.0	95.4–114.4	80.1
1¼	7 UNC	0.969	56.2–77.5	34.9	72.7–92.1	53.3	121–145	102
1½	6 UNC	1.405	81.5–112.4	50.6	105.0–133.0	77.3	176–216	148
1¾	5 UNC	1.90	110–152	68.4	142–180	104.5	238–285	200
2	4½ UNC	2.50	145–200	90.0	188–238	138	312–375	262
2¼	4½ UNC	3.25	188–260	117	244–309	179	406–488	341
2½	4 UNC	4.0	232–320	144	300–380	220	500–600	420
2¾	4 UNC	4.93	286–394	177	370–468	271	616–740	518
3	4 UNC	5.97	346–478	215	448–567	328	746–896	627
3¼	4 UNC	7.10	412–568	256	532–674	390	. . .	. . .
3½	4 UNC	8.33	483–666	300	625–791	458	. . .	. . .
3¾	4 UNC	9.66	560–773	348	724–918	531	. . .	. . .
4	4 UNC	11.08	643–886	399	831–1053	609	. . .	. . .
8 Thread Series (8 UN)[D]								
1⅛	8 UN	0.790	45.8–63.2	28.4	59.2–75.0	43.4	98.8–118.5	83.0
1¼	8 UN	1.000	58.0–80.0	36.0	75.0–95.0	55.0	125–150	105
1½	8 UN	1.492	86.5–119.4	53.7	112–142	82.1	186–224	157
1¾	8 UN	2.08	121–166	74.9	156–198	114	260–312	218
2	8 UN	2.77	161–222	99.7	208–263	152	346–416	291
2¼	8 UN	3.56	206–285	128	267–338	196	445–534	374
2½	8 UN	4.44	258–355	160	333–422	244	555–666	466
2¾	8 UN	5.43	315–434	195	407–516	299	679–815	570
3	8 UN	6.51	378–521	234	488–618	358	814–976	684
3¼	8 UN	7.69	446–615	277	577–731	423	. . .	. . .
3½	8 UN	8.96	520–717	323	672–851	493	. . .	. . .
3¾	8 UN	10.34	600–827	372	776–982	569	. . .	. . .
4	8 UN	11.81	685–945	425	886–1122	650	. . .	. . .

[A] Stress areas extracted from ANSI/ASME B 1.1.
[B] Tensile properties calculated from the tensile requirements given in Table 3.
[C] Yield strength measured at 0.2 % offset.
[D] Anchor bolts to 1¾ in. (44.5 mm) and larger with 8 UN threads and the nuts overtapped to the limits stated in 11.2.1 will not develop the tensile strength in Table 4 when the bolt and nut dimensions approach the minimum material limits of ANSI/ASME B 1.1 and B 18.2.2. See 11.2.1 for thread series that have been qualified for strength when the nuts are overtapped to the limits stated in 11.2.1.

anchor bolts, a lot shall consist of bars from the same heat, having the same diameter, and, if heat treated, heat treated in the same furnace lot.

13.2.2 *All Other Tests*—A lot is a quantity of product of one part number made by the same production process and subsequently submitted for final inspection at one time. The maximum lot size traceable to final inspection shall not be larger than 250 000 pieces.

13.3 *Test Frequency*:

13.3.1 The number of tests shall be as follows and in Table 7 and Table 8:

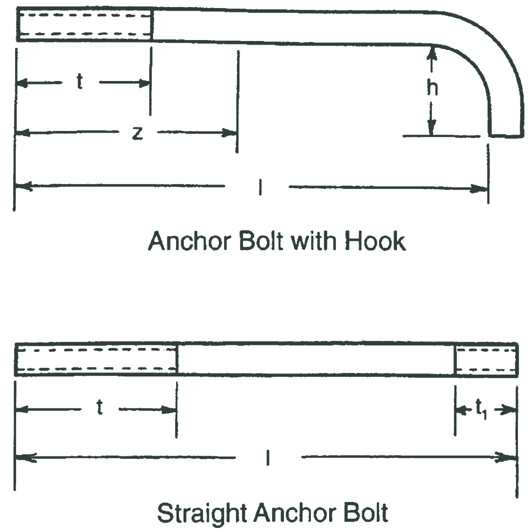
Test	Number of Tests
Composition	one per heat, minimum
Tensile tests	
Bar stock	one per lot, min, as defined in 13.2.1
Anchor bolts	in accordance with Table 7 and Table 8 on each lot defined in 13.2.2
Coating weight and thickness	
Dimensions	
Thread conformance	in accordance with Table 7 and Table 8 on each lot defined in 13.2.2
Workmanship	
Overall compliance	

TABLE 5 Minimum Body Diameter

Nominal Size, in.	Threads/ in.	Body Diameter, min, in.		
		Rolled Threads^A		Cut Threads^B Classes 1A and 2A
		Class 1A	Class 2A	
Unified Coarse Thread Series (UNC)				
¼	20 UNC	0.2108	0.2127	0.2367
⅜	16 UNC	0.3266	0.3287	0.3595
½	13 UNC	0.4411	0.4435	0.4822
⅝	11 UNC	0.5561	0.5589	0.6052
¾	10 UNC	0.6744	0.6773	0.7288
⅞	9 UNC	0.7914	0.7946	0.8523
1	8 UNC	0.9067	0.9100	0.9755
1⅛	7 UNC	1.0191	1.0228	1.0982
1¼	7 UNC	1.1439	1.1476	1.2232
1½	6 UNC	1.3772	1.3812	1.4703
1¾	5 UNC	1.6040	1.6085	1.7165
2	4½ UNC	1.8385	1.8433	1.9641
2¼	4½ UNC	2.0882	2.0931	2.2141
2½	4 UNC	2.3190	2.3241	2.4612
2¾	4 UNC	2.5686	2.5739	2.7111
3	4 UNC	2.8183	2.8237	2.9611
3¼	4 UNC	3.0680	3.0734	3.2110
3½	4 UNC	3.3177	3.3233	3.4610
3¾	4 UNC	3.5674	3.5730	3.7109
4	4 UNC	3.8172	3.8229	3.9609
8 Thread Series (8UN)				
1⅛	8 UN	. . .	1.0348	1.1004
1¼	8 UN	. . .	1.1597	1.2254
1½	8 UN	. . .	1.4093	1.4753
1¾	8 UN	. . .	1.6590	1.7252
2	8 UN	. . .	1.9087	1.9752
2¼	8 UN	. . .	2.1584	2.2251
2½	8 UN	. . .	2.4082	2.4751
2¾	8 UN	. . .	2.6580	2.7250
3	8 UN	. . .	2.9077	2.9749
3¼	8 UN	. . .	3.1575	3.2249
3½	8 UN	. . .	3.4074	3.4749
3¾	8 UN	. . .	3.6571	3.7248
4	8 UN	. . .	3.9070	3.9748

^A Minimum body diameter is the same as minimum pitch diameter. Extracted from ANSI/ASME B 1.1.

^B Minimum body diameter is the same as minimum major diameter. Extracted from ANSI/ASME B 1.1 for Class 1A and Footnote 5 for Class 2A.



h = length of hook
l = length of bolt
t = length of threads (exposed end)
t_1 = length of threads (encased end), when required
z = length of zinc coating, min, when partial zinc coating is required

FIG. 1 Anchor Bolt Dimensions

13.3.2 When the identity to a specific heat number (and furnace lot number for heat-treated bars) has not been maintained, the number of tests for all requirements, including tensile, shall be based on the quantity of anchor bolts of a given description as shown in Table 8.

13.3.3 Tensile tests on finished anchor bolts apply only when bar stock tests are not available or applicable or heat treatment is performed after threading or bending.

13.4 *Retests*—If a single nonconforming characteristic is found in final inspection, the lot may be resampled for this characteristic with a sample four times the size of the original final acceptance sample. The acceptance criterion shall then be zero discrepancies in this larger sample.

13.5 *Purchaser's Inspection*:

13.5.1 If, on receipt of anchor bolts, the purchaser discovers a single nonconforming part, he may sample the lot for such nonconforming characteristic(s) in accordance with 13.3 using an acceptance number of zero.

13.5.2 If the nonconforming characteristic in 13.5.1 is thread dimension and the anchor bolt manufacturer or supplier contests the findings, the final determination of thread acceptability shall be as follows: a full-size axial tension test shall be made on the threaded anchor bolt and nut assembly at the manufacturer's or supplier's expense. The assembly shall develop the tensile load specified in Table 4.

TABLE 6 Zinc Buildup on Coated Threads and Corresponding Thread Dimensions; Hot-Dip Zinc Coated in Accordance With Specification F 2329

Nominal Size, in.	Threads/in.	Diametral Zinc Buildup, in.^A	Anchor Bolt Diameter, max, in.	
			Major	Pitch
¼	20	0.016	0.2649	0.2324
⅜	16	0.017	0.3907	0.3501
½	13	0.018	0.5165	0.4685
⅝	11	0.020	0.6434	0.5844
¾	10	0.020	0.7682	0.7032
⅞	9	0.022	0.8951	0.8229
1	8	0.024	1.0220	0.9408
1⅛	8	0.024	1.1469	1.0657
1⅛	7	0.024	1.1468	1.0540
1¼	8	0.024	1.2719	1.1667
1¼	7	0.024	1.2718	1.5740
1½	8	0.027	1.5248	1.4436
1½	6	0.027	1.5246	1.4163
1¾	5	0.050	1.7973	1.6674
2	4.5	0.050	2.0471	1.9028
2¼	4.5	0.050	2.2971	2.1528
2½	4	0.050	2.5469	2.3845
2¾	4	0.050	2.7968	2.6344
3	4	0.050	3.0468	2.8844
3¼	4	0.050	3.2967	3.1343
3½	4	0.050	3.5467	3.3843
3¾	4	0.050	3.7966	3.6342
4	4	0.050	4.0466	3.8842

^A These values are the same as the overtap requirements for zinc-coated nuts given in Specification A 563.

14. Test Methods

14.1 *Chemical Composition*—Chemical analysis shall be conducted in accordance with Test Methods, Practices, and Terminology A 751.

TABLE 7 Inspection Level for Final Inspection[A]

Type of Test	Nondestructive Tests	Destructive Tests
Body diameter	C	. . .
Length	B	. . .
Head	C	. . .
Thread acceptance	B	. . .
Visual inspection[B]	A	. . .
Tensile properties	. . .	B
Coating weight/ Thickness	B	. . .

[A] Extracted from ANSI/ASME B 18.18.2M.
[B] Visual inspection for type identification, presence of finish, duds, surface discontinuities, and general workmanship.

TABLE 8 Number of Tests for Final Inspection[A]

Lot Size	Level of Inspection	Sample Size	
		Nondestructive Tests	Destructive Tests
999 and less	A	25	4
	B	8	2
	C	2	1
1 000 to 5 000	A	50	6
	B	16	3
	C	4	1
5 001 to 250 000	A	100	8
	B	32	4
	C	8	1

[A] Extracted from ANSI/ASME B 18.18.2M.

14.2 *Tensile Tests*:

14.2.1 Tensile tests on bars shall be conducted in accordance with Test Methods and Definitions A 370.

14.2.2 Tensile tests on finished anchor bolts shall be conducted in accordance with the Axial Tension Test Method in Methods F 606.

14.2.3 Yield strength shall be determined by the 0.2 % offset method.

14.2.4 Tension tests shall be conducted on the bar stock or finished anchor bolt at the manufacturer's or supplier's option but shall be conducted after the final heat treatment.

14.2.5 Grades 36 and 55 in sizes 1½ in. (38 mm) and less, and Grade 105 in sizes 1¼ in. (32 mm) and less, shall be tested using the full-bar section as rolled or the full-size finished anchor bolt.

14.2.6 Bars and finished anchor bolts larger than those specified in 14.2.5 shall preferably be tested full size, and when so tested the results shall be compared to the tensile properties given in Table 3 for bars and Table 4 for finished anchor bolts. When equipment for full-size testing of these larger sizes is not available, or when the length of the anchor bolt makes full-size testing impractical, standard 0.500-in. (12.7-mm) diameter machined test specimens shall be tested in accordance with Test Methods F 606 and the results compared to the tensile properties given in Table 3.

14.2.7 In the event that anchor bolts are tested by both full-size and machined test specimen methods, the full-size test shall govern if a discrepancy between the two methods exists.

14.3 *Zinc Coating*—Zinc coating weight and thickness shall be determined in accordance with the methods specified in the applicable zinc coating specifications referenced in 7.1.

15. Inspection

15.1 If the inspection described in 15.2 is required by the purchaser, it shall be specified in the inquiry and contract or order.

15.2 The inspector representing the purchaser shall have free entry to all parts of the manufacturer's works or supplier's place of business that concern the manufacture or supply of the material ordered. The manufacturer or supplier shall afford the inspector all reasonable facilities to satisfy him that the material is being furnished in accordance with this specification. All tests and inspections required by the specifications that are requested by the purchaser's representative shall be made before shipment and shall be conducted so as not to interfere unnecessarily with the operation of the works.

16. Rejection and Rehearing

16.1 Material that fails to conform to the requirements of this specification may be rejected. Rejection should be reported to the manufacturer or supplier promptly and in writing. In case of dissatisfaction with the results of the test, the manufacturer or supplier may make claim for a rehearing.

17. Certification

17.1 When specified in the purchase order, the manufacturer or supplier, whomever is the responsible party as specified in Section 18, shall furnish the purchaser a test report that includes the following:

17.1.1 Steel producer's heat analysis and heat number. The carbon equivalent shall be included for bars and anchor bolts ordered in accordance with Supplementary Requirement S 1.

17.1.2 Results of tensile tests.

17.1.3 Zinc coating, measured coating weight, and thickness.

17.1.4 Statement of compliance with dimensional and thread fit requirements.

17.1.5 Certification that the anchor bolts were manufactured and tested in accordance with this specification.

17.1.6 Lot number and purchase order number.

17.1.7 ASTM designation (including year), grade, and class.

17.1.8 Size, description, or purchaser's drawing number.

17.1.9 Complete mailing address or responsible party.

17.1.10 Title and signature of individual assigned certification responsibility by the company officers.

18. Responsibility

18.1 The party responsible for the fastener shall be the organization that supplies the fastener to the purchaser.

19. Product Marking

19.1 Unless otherwise specified (see Note 4), the end of each anchor bolt intended to project from the concrete shall be color coded to identify the grade as follows:

Grade	Color
36	Blue
55	Yellow
105	Red

NOTE 4—This color coding is intended to facilitate locating the proper grade of anchor bolt at its designed location. The color code also identifies

the grade at delivery and at final field inspection. When other color coding is required to define diameter, configuration, dimensions, etc., see 19.2.

19.2 When color coding other than specified in 19.1 is required, it shall be specified on the inquiry and purchase order.

19.3 When permanent manufacturers identification, or permanent grade identification, or both are required, Supplementary Requirement S2 or S3, or both, as needed, shall be specified on the inquiry and purchase order.

20. Packaging and Package Marking

20.1 *Packaging*:

20.1.1 Unless otherwise specified, packaging shall be in accordance with Practice D 3951.

20.1.2 When zinc-coated nuts are included on the same order as zinc-coated anchor bolts, the anchor bolts and nuts shall be shipped in the same container.

20.1.3 When special packaging requirements are required, they shall be defined at the time of the inquiry and order.

20.2 *Package Marking*:

20.2.1 Each shipping unit shall include or be marked plainly with the following information:

20.2.1.1 ASTM designation, Grade, and Class;

20.2.1.2 Size;

20.2.1.3 Name and brand or trademark of the manufacturer;

20.2.1.4 Number of pieces;

20.2.1.5 Lot number;

20.2.1.6 Purchase order number; and

20.2.1.7 Country of origin.

21. Keywords

21.1 anchor bolts; steel

SUPPLEMENTARY REQUIREMENTS

The following supplementary requirements shall apply only when specified in the purchase order or contract:

S1. Grade 55 Bars and Anchor Bolts

S1.1 The material described in this section is intended for welding. This supplemental section, by chemical composition restrictions and by a carbon equivalent formula, provides assurance of weldability.

S1.2 Welding technique is of fundamental importance when bolts produced to this supplementary section are welded. It is assumed that suitable welding procedures for the steel being welded and the intended service will be selected.

S1.3 The requirements of this supplementary requirement supersede conflicting provisions of the general specification.

S1.4 Because of the embrittling effects of welding temperatures on cold-forged steel, this supplemental section is limited to hot-forged bolts, or, if not forged, to the thread bars, studs, or bolts produced from hot-rolled bars without forging. Cold-forged bolts or cold-drawn threaded bars are suitable if they are given a thermal treatment by heating to a temperature of not less than 1500°F (815°C) and air-cooled.

S1.5 *Chemical Composition:*

S1.5.1 Steel shall conform to the following limitations:

	Heat Analysis	Product Analysis
Carbon, max, %	0.30	0.33
Manganese, max, %	1.35	1.41
Phosphorus, max, %	0.040	0.048
Sulfur, max, %	0.050	0.058
Silicon, max, %	0.50	0.55

S1.5.2 *Carbon Equivalent*—In addition to the requirements specified in S1.5.1, the analysis shall be such as to provide a carbon equivalent (CE) meeting the following requirements:

S1.5.2.1 For alloy or low-alloy steel, the carbon equivalent shall not exceed 0.45 % when calculated as follows:

$$CE = \% C + \frac{\% Mn}{6} + \frac{\% Cu}{40} + \frac{\% Ni}{20} + \frac{\% Cr}{10} - \frac{\% Mo}{50} - \frac{\% V}{10}$$

S1.5.2.2 For carbon steel, the carbon equivalent shall not exceed 0.40 % when calculated as follows:

$$CE = \% C + \frac{\% Mn}{4}$$

S1.6 Marking—Each anchor bolt conforming to this supplementary requirement S1 shall be designated by a white paint mark on the side of the bar near the end to be encased in concrete.

S2. Permanent Manufacturer's Identification

S2.1 The end of the anchor bolt intended to project from the concrete shall be steel die stamped with the manufacturer's identification. Marking small sizes (customarily less than 0.375 in. (9.525 mm)) may not be practical. Consult the anchor bolt manufacturer for the minimum size that can be marked.

S2.2 When required, grade and manufacturer's or private label distribution's identifications shall be separate and distinct. The two identifications shall preferably be in different locations and shall be separated by at least two spaces when on the same level.

S3. Permanent Grade Identification

S3.1 Instead of color coding as specified in 19.1, the end of the anchor bolt intended to project from the concrete shall be steel die stamped with the grade identification as follows:

Grade	Identification
36	AB36
55	AB55
105	AB105

S3.2 The requirements given in S2.1 for marking small sizes, and, in S2.2 that grade and manufacturer's identifications be separate and distinct, shall also apply to this supplementary requirement.

S4. Grades 55 and 105 Charpy Impact Requirements at +40°F (+5°C)

S4.1 Grades 55 and 105 shall have a Charpy V-Notch impact strength conforming to the requirements listed in Table S1.1.

S4.2 Tests shall be conducted in accordance with Test Methods and Definitions A 370.

S4.3 Notch toughness tests shall be performed at the Test Frequency P (Piece Testing) of Specification A 673/A 673M on finished anchor bolts when the results of notch toughness tests are not available on bar stock.

TABLE S1.1 Energy and Test Temperature Requirements

Charpy V-Notch Energy Requirements		Test Temperature, °F (°C)
Average for 3 Specimens, min, ft·lbf (J)	Minimum for 1 Specimen, ft·lbf (J)	
15 (20)	12 (16)	+40 (5)

TABLE S1.2 Energy and Test Temperature Requirements

Charpy V-Notch Energy Requirements		Test Temperature, °F (°C)
Average for 3 Specimens, min, ft·lbf (J)	Minimum for 1 Specimen, ft·lbf (J)	
15 (20)	12 (16)	−20 (29)

S4.4 Notch toughness tests shall be performed at the Test Frequency H (Heat Lot Testing) of Specification A 673/A 673M on bar stock, except when heat treatment is performed after threading or bending, in which case the tests shall be those required in S4.3.

S5. Grade 105 Charpy Impact Requirements at −20°F (−29°C)

S5.1 Grade 105 shall have Charpy V Notch impact strength conforming to the requirements listed in Table S1.2.

S5.2 Test methods and frequency of testing shall be as specified in S4.2 through S4.4.

SUMMARY OF CHANGES

Committee F16 has identified the location of selected changes to this standard since the last issue (F 1554–07) that may impact the use of this standard. (Approved Dec. 1, 2007.)

(*1*) Sections 7.1, 7.1.3, 7.1.4, and 11.2 were revised.

Committee F16 has identified the location of selected changes to this standard since the last issue, F 1554 – 04$^{\epsilon 1}$, that may impact the use of this standard. (Approved Aug. 1, 2007)

(*1*) Changed the reference hot dip zinc coating Specification from Specification A 153/A 153M Gr. C, to Specification F 2329.

Designation: A 307 – 07b

Standard Specification for Carbon Steel Bolts and Studs, 60 000 PSI Tensile Strength[1]

This standard is issued under the fixed designation A 307; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 This specification[2] covers the chemical and mechanical requirements of three grades of carbon steel bolts and studs in sizes ¼ in. through 4 in. The fasteners are designated by "Grade" denoting tensile strength and intended use, as follows:

Grade	Description
Grade A	Bolts and studs having a minimum tensile strength of 60 ksi and intended for general applications,
Grade B	Bolts and studs having a tensile strength of 60 to 100 ksi and intended for flanged joints in piping systems with cast iron flanges, and
Grade C	Replaced by Specification F 1554 Gr.36

1.1.1 The term *studs* includes stud stock, sometimes referred to as *threaded rod.*

1.2 This specification does not cover requirements for machine screws, thread cutting/forming screws, mechanical expansion anchors or similar externally threaded fasteners.

1.3 Suitable nuts are covered in Specification A 563. Unless otherwise specified, the grade and style of nut for each grade of fastener, of all surface finishes, shall be as follows:

Fastener Grade and Size	Nut Grade and Style[A]
A ¼ to 1½ in.	A, hex
A over 1½ to 4 in.	A, heavy hex
B, ¼ to 4 in.	A, heavy hex

[A] Nuts of other grades and styles having specified proof load stresses (Specification A 563, Table 3) greater than the specified grade and style of nut are also suitable.

1.4 The values stated in inch-pound units are to be regarded as the standard.

1.5 Supplementary Requirement S1 of an optional nature is provided, which describes additional restrictions to be applied when bolts are to be welded. It shall apply only when specified in the inquiry, order, and contract.

1.6 Terms used in this specification are defined in Terminology F 1789 unless otherwise defined herein.

2. Referenced Documents

2.1 *ASTM Standards:* [3]

A 563 Specification for Carbons and Alloy Steel Nuts

A 706/A 706M Specification for Low-Alloy Steel Deformed and Plain Bars for Concrete Reinforcement

A 751 Test Methods, Practices, and Terminology for Chemical Analysis of Steel Products

B 695 Specification for Coatings of Zinc Mechanically Deposited on Iron and Steel

D 3951 Practice for Commercial Packaging

F 606 Test Methods for Determining the Mechanical Properties of Externally and Internally Threaded Fasteners, Washers, Direct Tension Indicators, and Rivets

F 1470 Guide for Fastener Sampling for Specified Mechanical Properties and Performance Inspection

F 1554 Specification for Anchor Bolts, Steel, 36, 55, and 105-ksi Yield Strength

F 1789 Terminology for F16 Mechanical Fasteners

F 2329 Specification for Zinc Coating, Hot-Dip, Requirements for Application to Carbon and Alloy Steel Bolts, Screws, Washers, Nuts, and Special Threaded Fasteners

2.2 *ASME Standards:*

B 1.1 Unified Screw Threads[4]

B 18.2.1 Square and Hex Bolts and Screws[4]

B 18.24 Part Identifying Number (PIN) Code System[5]

3. Ordering Information

3.1 Orders for externally threaded fasteners (including nuts and accessories) under this specification shall include the following:

3.1.1 ASTM designation and year of issue,

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[1] This specification is under the jurisdiction of ASTM Committee F16 on Fasteners and is the direct responsibility of Subcommittee F16.02 on Steel Bolts, Nuts, Rivets and Washers.

Current edition approved Dec. 1, 2007. Published January 2008. Originally approved in 1947. Last previous edition approved in 2007 as A 307 – 07a.

[2] For *ASME Boiler and Pressure Vessel Code* applications see related Specification SA-307 in Section II of that Code.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[4] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036.

[5] Available from American Society of Mechanical Engineers (ASME), ASME International Headquarters, Three Park Ave., New York, NY 10016-5990.

***A Summary of Changes section appears at the end of this standard.**

3.1.2 Name of product, bolts or studs; and bolt head style, that is, hex or heavy hex,

3.1.3 Grade, that is, A, or B. If no grade is specified, Grade A is furnished.

3.1.4 Quantities (number of pieces by size including nuts),

3.1.5 Fastener size and length,

3.1.6 *Washers*—Quantity and size (separate from bolts),

3.1.7 *Zinc Coating*—Specify the zinc-coating process required, for example, hot-dip, mechanically deposited, or no preference (see 4.5).

3.1.8 *Other Finishes*—Specify other protective finish, if required.

3.1.9 Specify if inspection at point of manufacture is required,

3.1.10 Specify if certified test report is required (see 8.2), and

3.1.11 Specify additional testing (8.3) or special requirements.

3.1.12 For establishment of a part identifying system, see ASME B 18.24.

4. Materials and Manufacture

4.1 Steel for bolts and studs shall be made by the open-hearth, basic-oxygen, or electric-furnace process.

4.2 Bolts shall be produced by hot or cold forging of the heads or machining from bar stock.

4.3 *Heat Treatment:*

4.3.1 Cold headed fasteners with head configurations other than hex shall be stress relief annealed.

4.3.2 Stress relieving of hex head fasteners shall be at the manufacturer's option.

4.4 Bolt and stud threads shall be rolled or cut.

4.5 *Zinc Coatings, Hot-Dip and Mechanically Deposited*:

4.5.1 When zinc-coated fasteners are required, the purchaser shall specify the zinc-coating process, for example hot dip, mechanically deposited, or no preference.

4.5.2 When hot-dip is specified, the fasteners shall be zinc-coated by the hot-dip process in accordance with the requirements of Specification F 2329.

4.5.3 When mechanically deposited is specified, the fasteners shall be zinc-coated by the mechanical-deposition process in accordance with the requirements of Class 55 of Specification B 695.

4.5.4 When no preference is specified, the supplier may furnish either a hot-dip zinc coating in accordance with Specification F 2329, or a mechanically deposited zinc coating in accordance with Specification B 695, Class 55. Threaded components (bolts and nuts) shall be coated by the same zinc-coating process and the supplier's option is limited to one process per item with no mixed processes in a lot.

5. Chemical Composition

5.1 Grade A and B bolts and studs shall have a heat analysis conforming to the requirements specified in Table 1 based on the steel producer's heat analysis.

5.2 The purchaser shall have the option of conducting product analyses on finished bolts in each lot, which shall conform to the product analysis specified in Table 1.

TABLE 1 Chemical Requirements for Grades A and B Bolts and Studs

	Heat Analysis	Product Analysis
Carbon, max	0.29	0.33
Manganese, max	1.20	1.25
Phosphorus, max	0.04	0.041
Sulfur, max		
Grade A	0.15	A
Grade B	0.05	0.051

A Resulfurized steel is not subject to rejection based on product analysis for sulfur.

5.3 In case of conflict or for referee purposes, the product analysis shall take precedence.

5.4 Bolts and studs are customarily furnished from stock, in which case individual heats of steel cannot be identified.

5.5 Application of heats of steel to which bismuth, selenium, tellurium, or lead has been intentionally added shall not be permitted for Grade B bolts and studs.

5.6 Chemical analyses shall be performed in accordance with Test Methods, Practices, and Terminology A 751.

6. Mechanical Properties

6.1 Grades A and B bolts and studs shall conform to the hardness specified in Table 2.

6.2 Grade A and B bolts and studs 1½ in. in diameter or less, other than those excepted in 6.4, shall be tested full size and shall conform to the requirements for tensile strength specified in Table 3.

6.3 Grade A and B bolts and studs larger than 1½ in. in diameter, other than those excepted in 6.4, shall preferably be tested full size and when equipment of sufficient capacity is available and shall conform to the requirements for tensile strength specified in Table 3. When equipment of sufficient capacity for full-size bolt testing is not available, or when the length of the bolt makes full-size testing impractical, machined specimens shall be tested and shall conform to the requirements specified in Table 4.

6.4 Grades A and B bolts and studs less than three diameters in length or bolts with drilled or undersize heads are not subject to tensile tests.

6.5 In the event that bolts are tested by both full size and by machine test specimen methods, the full-size test shall govern if a controversy between the two methods exists.

6.6 For bolts and studs on which both hardness and tension tests are performed, acceptance based on tensile requirements

TABLE 2 Hardness Requirements for Bolts and Studs

Grade	Length, in.	Hardness[A]			
		Brinell		Rockwell B	
		min	max	min	max
A	Less than 3 × dia[B]	121	241	69	100
	3 × dia and longer	...	241	...	100
B	Less than 3 × dia[B]	121	212	69	95
	3 × dia and longer	...	212	...	95

A As measured anywhere on the surface or through the cross section.

B Also bolts with drilled or undersize heads. These sizes and bolts with modified heads shall meet the minimum and maximum hardness as hardness is the only requirement.

TABLE 3 Tensile Requirements for Full-Size Bolts and Studs

Bolt Size, in.	Threads per inch	Stress Area,[A] in.^{2}	Tensile Strength, lbf[B]		
			Grade A, min[C]	Grade B	
				min[D]	max[D]
1/4	20	0.0318	1 900	1 900	3 180
5/16	18	0.0524	3 100	3 100	5 240
3/8	16	0.0775	4 650	4 650	7 750
7/16	14	0.1063	6 350	6 350	10 630
1/2	13	0.1419	8 500	8 500	14 190
9/16	12	0.182	11 000	11 000	18 200
5/8	11	0.226	13 550	13 550	22 600
3/4	10	0.334	20 050	20 050	33 400
7/8	9	0.462	27 700	27 700	46 200
1	8	0.606	36 350	36 350	60 600
1 1/8	7	0.763	45 800	45 800	76 300
1 1/4	7	0.969	58 150	58 150	96 900
1 3/8	6	1.155	69 300	69 300	115 500
1 1/2	6	1.405	84 300	84 300	140 500
1 3/4	5	1.90	114 000	114 000	190 000
2	4 1/2	2.50	150 000	150 000	250 000
2 1/4	4 1/2	3.25	195 000	195 000	325 000
2 1/2	4	4.00	240 000	240 000	400 000
2 3/4	4	4.93	295 800	295 800	493 000
3	4	5.97	358 200	358 200	597 000
3 1/4	4	7.10	426 000	426 000	710 000
3 1/2	4	8.33	499 800	499 800	833 000
3 3/4	4	9.66	579 600	579 600	966 000
4	4	11.08	664 800	664 800	1 108 000

[A] Area calculated from the equation:

$$A_s = 0.7854\,[D - (0.9743/n)]^2$$

where:

A_s = stress area,
D = nominal diameter of bolt, and
n = threads per inch.

[B] 1 lbf = 4.448 N.
[C] Based on 60 ksi (414 MPa).
[D] Based on 60–100 ksi (414–690 MPa).

TABLE 4 Tensile Requirements for Machined Specimens

	Grade A	Grade B
Tensile strength, ksi	60 min	60–100
Yield point, min ksi	. . .	. . .
Elongation in 2 in., min, %	18	18

shall take precedence in the event that there is controversy over low readings of hardness tests.

7. Dimensions

7.1 Unless otherwise specified, threads shall be the Coarse Thread Series as specified in the latest issue of ASME B 1.1, and shall have a Class 2A tolerance.

7.2 Unless otherwise specified, Grade A bolts shall be hex bolts with dimensions as given in the latest issue of ASME B 18.2.1. Unless otherwise specified, Grade B bolts shall be heavy hex bolts with dimensions as given in the latest issue of ASME B 18.2.1.

7.3 Unless otherwise specified, bolts and studs to be used with nuts or tapped holes which have been tapped oversize, in accordance with Specification A 563, shall have Class 2A threads before hot-dip or mechanically deposited zinc coating. After zinc coating the maximum limit of pitch and major diameter shall not exceed the Class 2A maximum limit by more than the following amounts:

Diameter, in.	Oversize Limit, in. (mm)[A]
1/4	0.016
5/16 , 3/8	0.017
7/16 , 1/2	0.018
9/16 to 3/4 , incl	0.020
7/8	0.022
1.0 to 1 1/4 , incl	0.024
1 3/8 , 1 1/2	0.027
1 3/4 to 4.0, incl	0.050

[A] These values are the same as the overtapping required for zinc-coated nuts in Specification A 563.

7.4 The gaging limit for bolts and studs shall be verified during manufacture or use by assembly of a nut tapped as nearly as practical to the amount oversize shown above. In case of dispute, a calibrated thread ring gage of that same size (Class X tolerance, gage tolerance plus) shall be used. Assembly of the gage, or the nut described above, must be possible with hand effort following application of light machine oil to prevent galling and damage to the gage. These inspections, when performed to resolve disputes, shall be performed at the frequency and quality described in Table 5.

8. Number of Tests and Retests

8.1 The requirements of this specification shall be met in continuous mass production for stock, and the manufacturer shall make sample inspections to ensure that the product conforms to the specified requirements. Additional tests of individual shipments of material are not ordinarily contemplated. Individual heats of steel are not identified in the finished product.

8.2 When specified in the order, the manufacturer shall furnish a test report certified to be the last completed set of mechanical tests for each stock size in each shipment.

8.3 When additional tests are specified on the purchase order, a lot, for purposes of selecting test samples, shall consist of all material offered for inspection at one time that has the following common characteristics:

8.3.1 One type of item,

8.3.2 One nominal size, and

8.3.3 One nominal length of bolts and studs.

8.4 From each lot, the number of tests for each requirement shall be as follows:

TABLE 5 Sample Sizes and Acceptance Numbers for Inspection of Hot-Dip or Mechanically Deposited Zinc-Coated Threads

Lot Size	Sample Size[A]	Acceptance Number
2 to 90	13	1
91 to 150	20	2
151 to 280	32	3
281 to 500	50	5
501 to 1 200	80	7
1 201 to 3 200	125	10
3 201 to 10 000	200	14
10 001 and over	315	21

[A] Inspect all bolts in the lot if the lot size is less than the sample size.

Number of Pieces in Lot	Number of Samples
800 and under	1
801 to 8 000	2
8 001 to 22 000	3
Over 22 000	5

8.5 If any machined test specimen shows defective machining it shall be discarded and another specimen substituted.

8.6 Should any sample fail to meet the requirements of a specified test, double the number of samples from the same lot shall be tested, in which case all of the additional samples shall meet the specification.

9. Test Methods

9.1 Grades A and B bolts and studs shall be tested in accordance with Test Methods F 606.

9.2 Standard square and hex head bolts only shall be tested by the wedge tension method except as noted in 6.4. Fracture shall be in the body or threads of the bolt without any fracture at the junction of the head and body. Other headed bolts shall be tested by the axial tension method.

9.3 Speed of testing as determined with a free running crosshead shall be a maximum of 1 in./min for the tensile strength tests of bolts.

10. Inspection

10.1 If the inspection described in 10.2 is required by the purchaser it shall be specified in the inquiry, order, or contract.

10.2 The inspector representing the purchaser shall have free entry to all parts of the manufacturer's works that concern the manufacture of the material ordered. The manufacturer shall afford the inspector all reasonable facilities to satisfy him that the material is being furnished in accordance with this specification. All tests and inspections required by the specification that are requested by the purchaser's representative shall be made before shipment, and shall be conducted as not to interfere unnecessarily with the operation of the works.

11. Responsibility

11.1 The party responsible for the fastener shall be the organization that supplies the fastener to the purchaser.

12. Rejection and Rehearing

12.1 Disposition of nonconforming lots shall be in accordance with Guide F 1470, specifically sections on disposition of nonconforming lots, suppliers option, and purchasers option.

13. Product Marking

13.1 *Grades A and B Bolts and Studs*:

13.1.1 Bolt heads and one end of studs shall be marked with a unique identifier by the manufacturer to identify the manufacturer or private label distributor, as appropriate. Additional marking required by the manufacturer for his own use shall be at the option of the manufacturer.

13.1.2 In addition to the requirements of 13.1, all bolt heads, one end of studs ⅜ in. and larger, and whenever feasible studs less than ⅜ in. shall be marked with a grade marking as follows:

Grade	Marking
A	307A
B	307B

13.1.3 All markings shall be located on the top of the bolt head or stud end and shall be raised or depressed at the option of the manufacturer.

14. Packaging and Package Marking

14.1 *Packaging*:

14.1.1 Unless otherwise specified, packaging shall be in accordance with Practice D 3951.

14.1.2 When special packaging requirements are required, they shall be defined at the time of the inquiry and order.

14.2 *Package Marking*:

14.2.1 Each shipping unit shall include or be plainly marked with the following information:

14.2.1.1 ASTM designation and grade,

14.2.1.2 Size,

14.2.1.3 Name and brand or trademark of the manufacturer,

14.2.1.4 Number of pieces,

14.2.1.5 Purchase order number,

14.2.1.6 Country of origin.

15. Keywords

15.1 bolts; carbon steel; steel; studs

SUPPLEMENTARY REQUIREMENTS

The following supplementary requirement shall apply only when specified in the purchase order or contract:

S1. Bolts Suitable for Welding

S1.1 The material described in this section is intended for welding. This supplemental section, by additional chemical composition restrictions and by a carbon equivalent formula, provides assurance of weldability by chemical composition control.

S1.2 Welding technique is of fundamental importance when bolts produced to this supplementary section are welded. It is presupposed that suitable welding procedures for the steel being welded and the intended service will be selected.

S1.3 All of the requirements of this supplemental section apply in addition to all of the chemical, mechanical, and other requirements of the base specification, Specification A 307 for Grade B.

S1.4 Because of the embrittling effects of welding temperatures on cold-forged steel, this supplemental section is limited to hot-forged bolts, or, if not forged, then to bolts produced from hot-rolled bars without forging or threaded bars, bars studs, or stud bolts produced from hot-rolled bars without forging. Cold-forged bolts, or cold-drawn threaded bars, if they are given a thermal treatment by heating to a temperature of not less than 1500°F (815°C) and air-cooled are also suitable.

S1.5 *Chemical Requirements:*

S1.5.1 *Heat Chemical Analysis*—Material conforming to the following additional analysis limitations shall be used to manufacture the product described in this supplementary requirement.

Carbon	0.30 %, max
Manganese	1.00 %, max
Phosphorus	0.04 %, max
Sulfur	0.05 %, max
Silicon	0.50 %, max

S1.5.2 *Carbon Equivalent (Source—Specification A 706/A 706M)*—In addition to the heat chemical analysis requirements in S1.5.1, the heat analysis shall be such as to provide a carbon equivalent (CE) not exceeding 0.55 when calculated as follows:

$$CE = \% C + \frac{\% Mn}{6} + \frac{\% Cu}{40} + \frac{\% Ni}{20} + \frac{\% Cr}{10} - \frac{\% Mo}{50} - \frac{\% V}{10}$$

S1.6 *Analysis Reports*—If requested on the order or contract, the chemical composition of each heat of steel used and the calculated carbon equivalent for each heat shall be reported to the purchaser.

S1.7 *Product (Check) Verification Analysis*—Chemical analyses when made by the purchaser or a representative on bolts from each heat of steel, shall not exceed the values specified in S1.5.2 by more than the following amounts:

	%
Carbon	+0.03
Manganese	+0.06
Phosphorus	+0.008
Sulfur	+0.008
Silicon	+0.05

S2. Permanent Manufacturer's Identification

S2.1 Replaced by Specification F 1554.

S3. Permanent Grade Identification

S3.1 Replaced by Specification F 1554.

SUMMARY OF CHANGES

Committee F16 has identified the location of selected changes to this standard since the last issue (A 307–07a) that may impact the use of this standard. (Approved Dec. 1, 2007.)

(*1*) Sections 4.5.3 and 4.5.4 were revised.

Committee F16 has identified the location of selected changes to this standard since the last issue (A 307–07) that may impact the use of this standard. (Approved Aug. 1, 2007.)

(*1*) Changed the reference hot dip zinc coating specification from Specification A 153/A 153M to Gr. C to Specification F 2329.

Committee F16 has identified the location of selected changes to this standard since the last issue (A 307–04) that may impact the use of this standard. (Approved June 15, 2007.)

(*1*) Revised 1.1 Gr. C anchor bolts, and all related sections, to delete anchor bolts and replaced with reference to Specification F 1554 Gr. 36.