Designation: E488/E488M – 15

Standard Test Methods for Strength of Anchors in Concrete Elements[1]

This standard is issued under the fixed designation E488/E488M; 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 U.S. Department of Defense.

1. Scope

1.1 These test methods address the tensile and shear strengths of post-installed and cast-in-place anchors in test members made of cracked or uncracked concrete. Loadings include quasi-static, seismic, fatigue and shock. Environmental exposures include freezing and thawing, moisture, decreased and elevated temperatures and corrosion. These test methods provide basic testing procedures for use with product-specific evaluation and acceptance standards and are intended to be performed in a testing laboratory. Product-specific evaluation and acceptance standards may add specific details and appropriate parameters as needed to accomplish the testing. Only those tests required by the specifying authority need to be performed.

1.2 These test methods are intended for use with post-installed and cast-in-place anchors designed for installation perpendicular to a plane surface of a test member.

1.3 This standard prescribes separate procedures for static, seismic, fatigue and shock testing. Nothing in this standard, however, shall preclude combined tests incorporating two or more of these types of loading (such as seismic, fatigue and shock tests in series).

1.4 Both inch-pound and SI units are provided in this standard. The testing may be performed in either system and reported in that system and the results converted to the other. However, anchor diameters, threads, and related testing equipment shall be in accordance with either inch-pound or SI provisions.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C31/C31M Practice for Making and Curing Concrete Test Specimens in the Field
C33/C33M Specification for Concrete Aggregates
C39/C39M Test Method for Compressive Strength of Cylindrical Concrete Specimens
C42/C42M Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete
C150/C150M Specification for Portland Cement
C330/C330M Specification for Lightweight Aggregates for Structural Concrete
E4 Practices for Force Verification of Testing Machines
E8/E8M Test Methods for Tension Testing of Metallic Materials
E468 Practice for Presentation of Constant Amplitude Fatigue Test Results for Metallic Materials
E575 Practice for Reporting Data from Structural Tests of Building Constructions, Elements, Connections, and Assemblies
E631 Terminology of Building Constructions
E2265 Terminology for Anchors and Fasteners in Concrete and Masonry
F606/F606M Test Methods for Determining the Mechanical Properties of Externally and Internally Threaded Fasteners, Washers, Direct Tension Indicators, and Rivets
F1624 Test Method for Measurement of Hydrogen Embrittlement Threshold in Steel by the Incremental Step Loading Technique
G5 Reference Test Method for Making Potentiodynamic Anodic Polarization Measurements

2.2 *ANSI Standards:*[3]

ANSI B212.15 American National Standard for Cutting Tools—Carbide-Tipped Masonry Drills and Blanks for Carbide-Tipped Masonry Drills

[1] These test methods are under the jurisdiction of ASTM Committee E06 on Performance of Buildings and are the direct responsibility of Subcommittee E06.13 on Structural Performance of Connections in Building Construction.

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[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 American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of general terms related to building construction used in this standard, refer to Terminology E631, and for definitions of terms related to anchoring, refer to Terminology E2265.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *load-controlled undercut anchor, n*—a post-installed anchor that derives its tensile holding strength by the mechanical interlock provided by installing the anchor by tensioning, which causes the sleeve to expand into the predrilled undercut.

3.2.2 *post-installed anchor, n*—an anchor that is installed after the placement and hardening of concrete.

3.2.3 *run-out, n*—a condition in which failure does not occur within the specified number of load cycles in a fatigue test.

3.2.4 *standard temperature, n*—73°F [23°C] ± 8°F [6°C].

3.2.5 *test member, n*—the base material in which the anchor is installed and which resists forces from the anchor.

3.3 *Symbols:*

c_a = distance from the center of an anchor shaft to the edge of test member, in. [mm].
c_{min} = minimum distance from the center of an anchor shaft to the edge of test member, determined from tests, in. [mm].
d = nominal diameter of anchor to be tested, in. [mm].
d_{fix} = diameter of hole in shear sleeve, ≥d, in. [mm].
d_{hole} = diameter of drilled borehole in test specimen, in. [mm].
d_m = diameter of carbide-tipped drill bit with diameter on low end of tolerance range for new bit, representing moderately used bit, in. [mm].
d_{max} = diameter of carbide-tipped drill bit with diameter on high end of tolerance range for new bit, representing bit as large as would be expected in use, in. [mm].
d_{min} = diameter of carbide-tipped drill bit with diameter below low end of tolerance range for new bit representing a well-used bit, in. [mm].
d_o = outside diameter of post-installed anchor, in. [mm].
$d_{opening}$ = diameter of hole in confining plate for confined tension tests, in. [mm].
F_{cr} = crack-inducing force, applied to reinforcing bars, lb [N].
f'_c = specified concrete compressive strength, psi [MPa].
$f'_{c,ref}$ = specified compressive strength of reference concrete test member, psi [MPa].
$f'_{c,test}$ = specified compressive strength of concrete test member, psi [MPa].
h_{ef} = effective embedment depth, measured from the concrete surface to the deepest point at which the anchor tension load is transferred to the concrete, in. [mm].
h_{min} = minimum member thickness, in. [mm].
h_{nom} = distance between embedded end of concrete screw and concrete surface, in. [mm].
n_{ct} = number of test cycles.
n_{pt} = number of permitted pretest crack cycles.
$N_{p,cr}$ = characteristic pullout resistance in cracked concrete for the minimum specified concrete strength of 2500 psi [17 MPa], as determined from tests in cracked concrete, lb [N].
$N_{st,mean}$ = mean ultimate steel capacity determined from tensile tests on full-sized anchor specimens, lb [N].
$N_{sust,l}$ = sustained load, lb [N].
$N_{sust,con}$ = sustained load used for confined reference tests, lb [N].
$N_{sust,ft}$ = specified constant tension load, lb [N].
$N_{u,con,mean}$ = mean ultimate load determined from confined reference tests, lb [N].
$N_{u,mean}$ = mean ultimate load determined from tests, lb [N].
N_w = tensile load in tests of anchors located in cracks whose opening width is cycled, lb [N].
s_{min} = minimum anchor spacing, determined from test, in. [mm].
t_{fix} = effective thickness of shear sleeves (see d), in. [mm].
t_{pl} = thickness of confining plate for tension tests, ≥d, in. [mm].
T_{inst} = specified or maximum setting torque for expansion or prestressing of an anchor, ft·lb [N·m].
T_{screw} = specified maximum setting torque to prevent anchor failure during installation, ft-lb [N-m].
W_1 = largest crack width during test, in. [mm].
W_2 = smallest crack width during test, in. [mm].
W_3 = largest crack width at beginning of test, in. [mm].
ℓ_{side} = side length of test cube, in. [mm].

4. Significance and Use

4.1 These test methods are intended to provide reproducible data from which acceptance criteria, design data, and specifications can be developed for anchors intended to be installed in concrete.

5. Apparatus

5.1 *Testing Equipment:*

5.1.1 *General*—Use calibrated electronic load and displacement measuring devices meeting the specified sampling rate. Use load-measuring equipment with an accuracy of ±1 % of the anticipated ultimate load and calibrated in accordance with Practices E4. Use displacement measuring devices with an accuracy of ±0.001 in. [±0.025 mm] and crack-width measuring devices with an accuracy of ±0.0005 in. [±0.013 mm]. For recording load and displacement measurements, use a data-acquisition system capable of recording at least 120 data points per instrument for each individual test, prior to reaching peak load. The testing equipment shall have sufficient capacity to prevent yielding of its components under the anticipated ultimate load, and shall have sufficient stiffness to ensure that the applied tension loads remain parallel to the axes of the anchors and that the applied shear loads remain parallel to the surface of the test member during testing.

5.1.2 *Tension Test Equipment*—The support for the tension test equipment shall be of sufficient size to prevent failure of the surrounding test member. The loading rod shall be of sufficient diameter to develop the anticipated ultimate strength of the anchorage hardware with an elastic elongation not exceeding 10 % of the anticipated elastic elongation of the anchor, and shall be attached to the anchorage system by a connector that will minimize the direct transfer of bending stress to the anchor. The displacement measuring device(s) shall be positioned to measure the movement of the anchors with respect to points on the test member so that the device is not influenced during the test by deflection or failure of the anchor or test member. See Fig. 1 and Fig. 2 for examples of typical test setups.

NOTE 1—Other support geometries are acceptable.

Table 1 gives the minimum required clear distance from the test support to the anchor for tension and shear loading.

5.1.3 *Shear Test Equipment*—Position the displacement-measuring device(s) to measure displacement in the direction of the applied load only. Place the device on the test member so that the sensing element bears perpendicularly on the anchor or on a contact plate located on the loading plate, or use another method that restricts deflections other than those in the direction of the applied load. See Fig. 4 for a typical example of a shear test setup. For tests on anchor groups, the axis of the displacement-measuring device shall coincide with the centroid of the group. Table 1 gives the minimum required clear distance from the test support to the anchor shear loading toward a free edge.

5.2 *Group Test Equipment*—Measure the simultaneous displacement of all anchors or groups of anchors tested. Only one set of displacement-measuring devices is required for a group of anchors. Displacement measurements as described in 5.1.1 include components of deformation not directly associated with displacement of the anchor relative to the test member, such as elastic elongation of the loading rod, deformation of the loading plate, sleeves, shims, attachment hardware, and local test member material. Using supplementary measuring devices or calibration test data for the installed test set-up with a rigid anchor replacing the anchor to be tested, identify such deformation components and subtract them from the total measured displacement. To evaluate the findings, use the average displacement indicated by the instruments in each group.

5.3 *Loading Plates:*

5.3.1 For tension loading the plate thickness t_{fix} in the immediate vicinity of the test anchor shall be equal to or greater than the nominal anchor diameter to be tested.

5.3.2 For shear testing the plate thickness t_{fix} in the immediate vicinity of the test anchor shall be equal to the nominal anchor diameter to be tested, –1⁄16 +1⁄8 in. [–1.5 +3.0 mm]. The hole in the loading plate shall have a diameter of 0.06 ± 0.03 in. [3.0 ± 1.5 mm] greater than the specified diameter of the test anchor unless another diameter is specified. The shape of the hole in the loading plate shall correspond to that of the anchor cross section. When sleeve inserts of the required diameter are used they shall be periodically inspected and replaced to meet these requirements and prevent eccentric loading of sleeve. See Fig. 5 for a representative shear plate with sleeves. The contact area between the loading plate through which the anchor is installed and the test member shall be as given in Table 2, unless otherwise specified. Chamfer or smooth the edges of the loading plate so that it does not dig into the concrete. Place a sheet of polytetrafluoroethylene (PTFE) or other friction-limiting materials with a minimum thickness of 0.020 in. [0.5 mm] between the loading plate and base

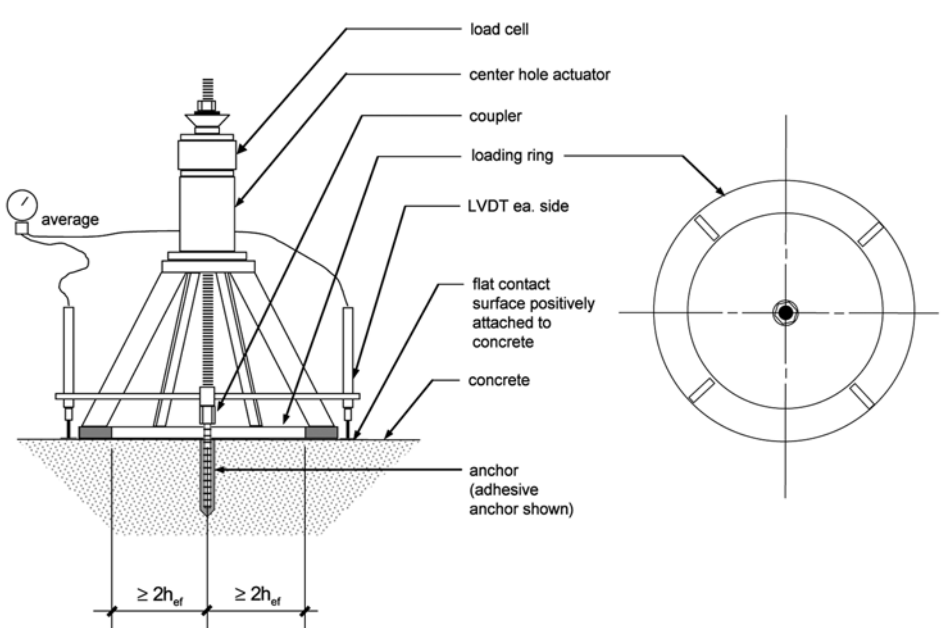


FIG. 1 Example of Unconfined Tension Test Setup – Displacement Measurement with Dual LVDTs

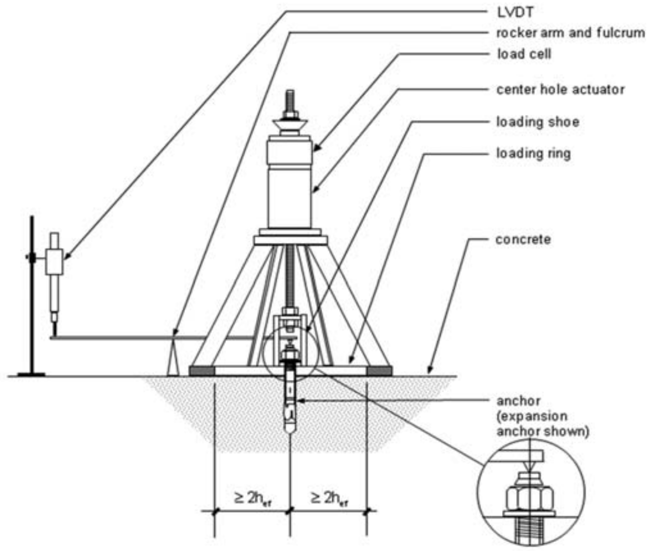


FIG. 2 Example of Unconfined Tension Test Setup – Displacement Measurement from top of Anchor

TABLE 1 Minimum Clearance Requirements for Test Equipment Supports

All Anchors	
Spacing Between Test Supports	Distance from Anchor to Edge of Test Support
Tension Loads	
4.0 h_{ef}	2.0 h_{ef}
Shear Loads	
4.0 c_a	2.0 c_a

material surface. The friction-limiting material shall prevent contact of the loading plate with the base material.

5.4 *Unconfined and Confined Test Equipment:*

5.4.1 *Unconfined Tests*—Fig. 1 and Fig. 2 show a typical unconfined tension test setup with supports spaced as required to permit the unrestricted development of a conical concrete fracture surface. The values given in Table 1 for required clearances between the anchor and the test support shall be considered to satisfy this requirement.

5.4.2 *Confined Tests*—Fig. 3 shows a typical confined tension test setup for anchors, in which the reaction force is transferred into the concrete close to the anchor. The confining plate shall have a hole with diameter between 1.5 d_{hole} and 2.0 d_{hole}, and a thickness $t_{fix} \geq d$. Place a sheet of polytetrafluoroethylene (PTFE) or other friction-limiting materials with a minimum thickness of 0.020 in. [0.5 mm] between the loading plate and base material surface. The friction-limiting material shall prevent contact of the confining plate with the base material.

5.5 *Cracked Concrete Testing:*

5.5.1 *Equipment for Controlling Cracks*—The test apparatus shall be capable of controlling the crack width. A typical tension test setup for cracked concrete is shown in Fig. 6.

NOTE 2—Fig. 6 shows testing of multiple anchors. Smaller test members can be used for testing single anchors.

6. Test Specimens

6.1 *Anchorage System*—The anchors or anchorage system shall be representative of the type and lot to be used in field construction, and shall include the attachment hardware normally required for use.

6.2 *Test Member*—The requirements of the test member in which the anchor is to be embedded and tested shall be specified. The location and orientation of any reinforcement embedded in concrete members shall meet the requirements of 6.3 and 6.4.

6.2.1 *Concrete Test Members:*

6.2.1.1 *Casting and Curing of Concrete Test Members*—Concrete used in testing shall meet the requirements of Sections 6.2.1.2 through 6.2.1.4 (*3*) (*b*) unless otherwise specified.

6.2.1.2 Cast test members either horizontally or vertically. If the member is cast vertically, the maximum height of a concrete lift shall be 5 ft [1.5 m]. In general, the thickness of the test member depends on the testing requirements. The test member shall be at least 1.5 h_{ef} thick, unless the specific test application requires a specific thickness.

6.2.1.3 *Surface Finish*—The surface of the test member shall be a formed or steel-troweled finish unless otherwise specified.

6.2.1.4 *Concrete for Test Members*—Concrete for test members shall meet the requirements of 6.2.1.4 (*1*) through 6.2.1.4 (*3*) (*b*).

(1) Aggregates—For normalweight concrete, use aggregates conforming to Specification C33/C33M, with a maximum size of 1 in. [25 mm] or Specification C330/C330M for lightweight concrete.

(2) Cement—Use only portland cement conforming to Specification C150/C150M for normalweight concrete or lightweight concrete, unless otherwise specified. If any other cementitious materials (for example, slag, fly ash, silica fume, or limestone powder) or chemical admixtures (for example, air-entraining agents, water reducers, high-range water

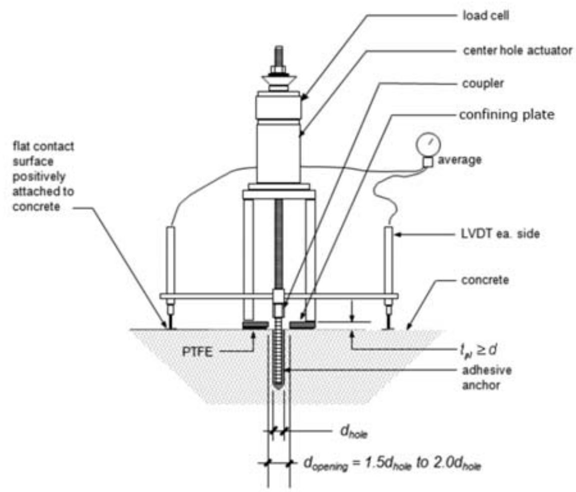


FIG. 3 Example of Confined Tension Test Setup – Adhesive Anchor Shown

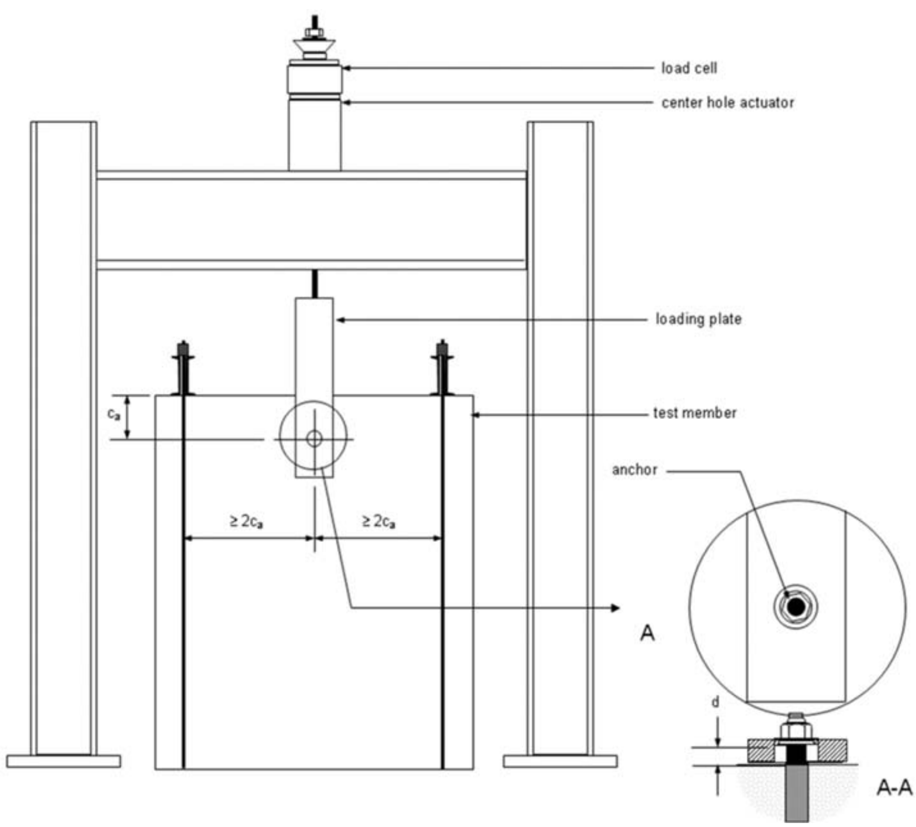


FIG. 4 Example of a Shear Test Setup

reducers, shrinkage-compensating admixtures, corrosion inhibitors, set retarders, and set accelerators) are used in the concrete test members, report them.

(3) Concrete Strength—Compressive strength specimens shall be prepared and tested in accordance with Practice C31/C31M and Test Method C39/C39M.

(a) Cure concrete cylinders in accordance with Practice C31/C31M or Test Method C39/C39M under the same environmental conditions as the test members. Remove molds from the cylinders at the same time that the forms are removed from the test members. Unless otherwise specified, at the time of anchor testing, the concrete shall be at least 21 days old.

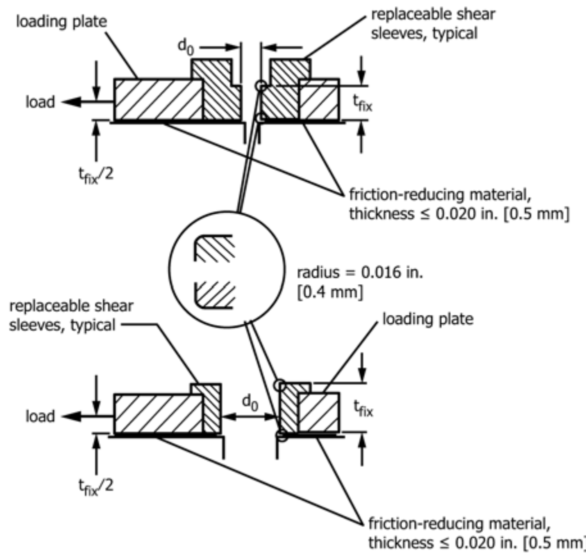


FIG. 5 Example of Shear Plate with Sleeves

TABLE 2 Shear Loading Plate Bearing Area as a Function of Anchor Diameter

Anchor Diameter, d_o in. [mm]	Shear Loading Plate Contact Area,[A,B] in.^{2} [cm^2]	
	minimum	maximum
<⅜ [<10]	8 [50]	12 [80]
⅜ ≤ d_o < ⅝ [16]	12 [80]	18 [115]
⅝ ≤ d_o < ⅞ [22]	18 [115]	25 [160]
⅞ ≤ d_o < 2 [50]	25 [160]	40 [260]
d_o≤ 2 [50]	40 [260]	60 [385]

[A] Shear loading plate contact area with PTFE or other friction-limiting material.
[B] Calculated uniform bearing stress on contact area due to self-weight of loading plate and associated loading apparatus shall not exceed 5 psi [0.03 MPa].

Establish the compressive strength of the concrete test member at the time of anchor testing by interpolation between the strengths of control samples at the start and at the end of testing, or at closer intervals as specified. Alternately, test enough control samples to plot a strength-versus-age graph, and use interpolation to estimate the concrete strength at the day of test.

(b) When evaluating the test results, if there is a question whether the strength of the concrete cylinders represents the concrete strength of the test member, verify the compressive strength of at least three cores with diameters from 3 to 6 in. [75 to 150 mm], taken from the test member outside of the zones where the concrete has been damaged by the anchor test. Prepare the core samples, test them in the dry condition, and evaluate the results in accordance with the provisions of Test Method C42/C42M.

6.3 *Uncracked Concrete Test Members*—Use test members that are unreinforced, except as permitted by 6.3.1.

6.3.1 The test member shall be permitted to contain reinforcement to allow handling, the distribution of loads transmitted by the test equipment, or both. Place such reinforcement so that the capacity of the tested anchor is not affected. This requirement shall be considered to be met if the reinforcement is located outside a cone of concrete whose vertex is at the anchor, whose base is perpendicular to the direction of load, and whose internal vertex angle is 120 degrees.

6.4 *Cracked Concrete Test Members*—Test members shall be permitted to contain reinforcement to allow handling, the distribution of loads transmitted by test equipment, or both. Place the reinforcement so that the capacity of the tested anchor is not affected. See Fig. 7 for a representative concrete test member for cracked concrete.

6.4.1 The crack width shall be approximately uniform throughout the member thickness. The thickness of the test member shall be not less than the greater of 1.5 h_{ef} and 4 in. [100 mm]. To control the location of cracks and to help ensure that the anchors are installed to the full depth in the crack, crack inducers shall be permitted to be installed in the member, provided that they are not situated so as to influence the test results. For test members that use internal reinforcement to control the crack width, place the reinforcement so that it does not influence the performance of the anchors. Use a cross-sectional reinforcement ratio of about 1 %. Reinforcement shall be permitted in the failure cone of concrete. The center-to-center distance between the reinforcement and the anchor shall be greater than 0.4 h_{ef}, and the center-to-center distance between adjacent top and bottom crack-control reinforcement shall not be less than 10 in. [250 mm].

7. General Testing Procedures

7.1 *Anchor Installation*—Install the anchors according to the manufacturer's instructions. Report the installation details according to 15.1.7.

7.2 *Anchor Placement*—Install anchors in a formed face of the concrete or in concrete with a steel-troweled finish.

7.3 *Drill Bit Requirements*—Drill holes with a hammer (rotary-percussive) drill using carbide-tipped, hammer-drill bits conforming to Table 3 or Table 4, unless otherwise specified. Table 3 is based on the requirements of ANSI B212.15. For core bits or other bits not covered by Table

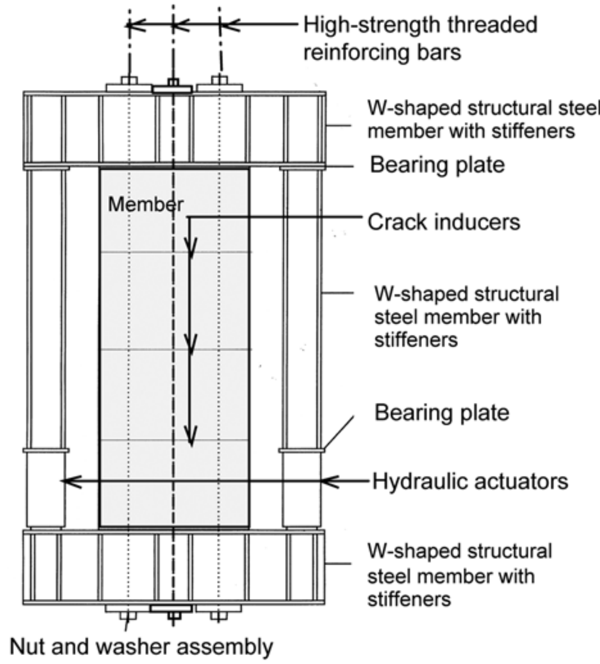


FIG. 6 Example of Test Setup for Cracked Concrete

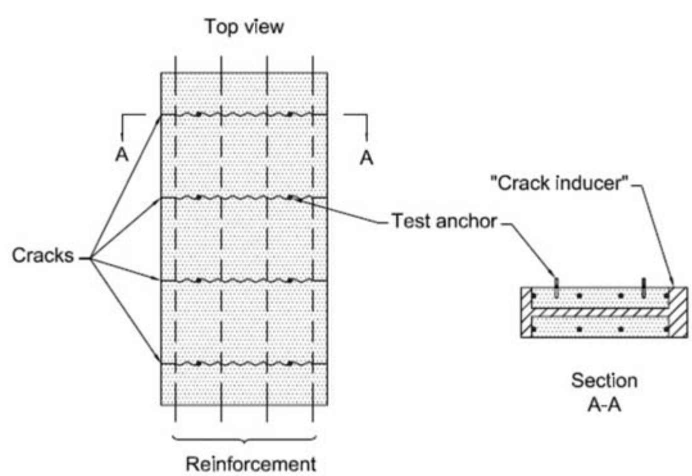


FIG. 7 Example of Test Member for Testing in Cracked Concrete

3 or Table 4, use a tolerance range analogous to that of Table 3 or Table 4 unless otherwise specified.

7.4 *Number of Anchor Test Specimens*—The minimum number of replicate anchor test specimens shall be specified as part of the testing program.

7.5 *Cracked Concrete Testing*—Use the procedure specified in 7.5.1 – 7.5.3 for testing anchors in cracked concrete.

7.5.1 Perform tests in concrete specimens meeting the requirements of 6.4, with the crack width *w* as specified for the given test. Initiate the crack and install the anchor in a closed crack according to 7.1 so that the axis of the anchor lies approximately in the plane of the crack. Install the measurement devices for measuring crack widths, and widen the crack by the specified crack width while the anchor is not loaded. Measure the crack opening using measurement devices oriented perpendicular to the crack.

7.5.2 Subject the anchor to the specified loading sequence while monitoring the crack width.

7.5.3 During the test, maintain a continuous record of the load applied to the anchor and displacement of the anchor, and for the crack cycling test, the crack width.

7.6 *Load Application:*

7.6.1 *Initial Load*—Apply an initial load up to 5 % of the estimated maximum load capacity of the anchorage system to be tested, in order to bring all members into full bearing.

7.6.2 *Rate of Loading*—Increase the load or displacement so that peak load occurs after 1 to 3 min from the start of testing.

TABLE 3 Required Diameters of Carbide Hammer-Drill Bits, US Customary Units

Nominal Diameter, in.	Tolerance Ranges		
	d_{min}, in.	d_m, in.	d_{max}, in.
1/4	0.252 to 0.256	0.260 to 0.263	0.266 to 0.268
5/16	0.319 to 0.323	0.327 to 0.331	0.333 to 0.335
3/8	0.381 to 0.385	0.390 to 0.393	0.396 to 0.398
7/16	0.448 to 0.452	0.458 to 0.462	0.465 to 0.468
1/2	0.510 to 0.514	0.520 to 0.524	0.527 to 0.530
9/16	0.573 to 0.577	0.582 to 0.586	0.589 to 0.592
5/8	0.639 to 0.643	0.650 to 0.654	0.657 to 0.660
11/16	0.702 to 0.706	0.713 to 0.717	0.720 to 0.723
3/4	0.764 to 0.768	0.775 to 0.779	0.784 to 0.787
13/16	0.827 to 0.831	0.837 to 0.841	0.846 to 0.849
27/32	0.858 to 0.862	0.869 to 0.873	0.878 to 0.881
7/8	0.892 to 0.896	0.905 to 0.909	0.914 to 0.917
15/16	0.955 to 0.959	0.968 to 0.972	0.977 to 0.980
1	1.017 to 1.021	1.030 to 1.034	1.039 to 1.042
1 1/8	1.145 to 1.149	1.160 to 1.164	1.172 to 1.175
1 3/16	1.208 to 1.212	1.223 to 1.227	1.235 to 1.238
1 1/4	1.270 to 1.274	1.285 to 1.289	1.297 to 1.300
1 5/16	1.333 to 1.337	1.352 to 1.356	1.364 to 1.367
1 3/8	1.395 to 1.399	1.410 to 1.414	1.422 to 1.425
1 7/16	1.458 to 1.462	1.472 to 1.476	1.484 to 1.487
1 1/2	1.520 to 1.524	1.535 to 1.539	1.547 to 1.550
1 9/16	1.570 to 1.574	1.588 to 1.592	1.605 to 1.608
1 5/8	1.637 to 1.641	1.655 to 1.659	1.673 to 1.675
1 3/4	1.754 to 1.758	1.772 to 1.776	1.789 to 1.792
2	1.990 to 1.994	2.008 to 2.012	2.025 to 2.028

TABLE 4 Required Diameters of Carbide Hammer-Drill Bits, SI Units

Nominal Diameter, mm	Tolerance Ranges		
	d_{min}, mm	d_m, mm	d_{max}, mm
6	6.05 to 6.15	6.20 to 6.30	6.35 to 6.40
7	7.05 to 7.20	7.25 to 7.35	7.40 to 7.45
8	8.05 to 8.20	8.25 to 8.35	8.40 to 8.45
10	10.10 to 10.20	10.25 to 10.35	10.40 to 10.45
11	11.10 to 11.20	11.25 to 11.35	11.45 to 11.50
12	12.10 to 12.20	12.25 to 12.35	12.45 to 12.50
13	13.10 to 13.20	13.25 to 13.35	13.45 to 13.50
14	14.10 to 14.20	14.25 to 14.35	14.45 to 14.50
15	15.10 to 15.20	15.25 to 15.35	15.45 to 15.50
16	16.10 to 16.20	16.25 to 16.35	16.45 to 16.50
18	18.10 to 18.20	18.25 to 18.35	18.45 to 18.50
19	19.10 to 19.20	19.30 to 19.40	19.50 to 19.55
20	20.10 to 20.20	20.30 to 20.40	20.50 to 20.55
22	22.10 to 22.20	22.30 to 22.40	22.50 to 22.55
24	24.10 to 24.20	24.30 to 24.40	24.50 to 24.55
25	25.10 to 25.20	25.30 to 25.40	25.50 to 25.55
28	28.10 to 28.20	28.30 to 28.40	28.50 to 28.55
30	30.10 to 30.20	30.30 to 30.40	30.50 to 30.55
32	32.15 to 32.25	32.35 to 32.50	32.60 to 32.70
34	34.15 to 34.25	34.35 to 34.50	34.60 to 34.70
35	35.15 to 35.25	35.35 to 35.50	35.60 to 35.70
37	37.15 to 37.25	37.35 to 37.50	37.60 to 37.70
40	40.15 to 40.25	40.40 to 40.60	40.70 to 40.80
44	44.15 to 44.25	44.40 to 44.60	44.70 to 44.80
48	48.15 to 48.25	48.40 to 48.60	48.70 to 48.80
52	52.15 to 52.25	52.40 to 52.60	52.80 to 52.95

7.6.3 *Control of Loading or the Displacement*—Conduct the test under load or displacement control. If the descending branch of the load-displacement curve is desired, use displacement-control.

7.7 *Data Recording*—Record load and displacement at a sampling rate sufficient to approximate continuous load and displacement curves and capture peak values. For static testing, a sampling rate of once per second shall be acceptable for satisfying this requirement.

8. Monotonic Load Tests

8.1 *Tension Load Tests in Uncracked Concrete:*

8.1.1 *Tension Tests for Single Anchors Without Edge and Spacing Effects:*

8.1.1.1 Center the loading system over the anchor or anchors to be tested so that test system supports meet the placement requirements of Table 1 (see Figs. 1-3). Provide uniform contact between the surface of the test member and the support system. In the final alignment of the support system, ensure that the forces to be applied through the loading rod are perpendicular to the surface of the test member section. The amount of torque or pretension applied to the anchor by the attaching nut or locking device and the procedure used shall be specified for each series of tests.

8.1.1.2 Unless otherwise specified, position and attach the loading rod so that the load shall be applied concentrically with the anchor axis. Where groups of anchors are to be loaded simultaneously through a common loading fixture, specify the details of the fixture's stiffness, rotational restraint, and point and angle of load application.

8.1.2 *Verification of Full Concrete Capacity in Corner with Two Edges*—This test requires that the loading apparatus be designed so as to permit an unrestricted concrete cone breakout failure at the corner (see Fig. 8). Where necessary to meet this requirement, the loading apparatus shall be supported outside the test member.

8.1.3 *Minimum Spacing and Edge Distance to Preclude Splitting*—Test anchors in uncracked 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 at a distance of at least $3h_{min}$ from other groups. Select s_{min}, c_{min}, and h_{min}, depending on the anchor characteristics.

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 center-line of the corresponding anchor shall be at least three times the anchor diameter.

8.1.3.1 For torque-controlled anchors, apply load to the anchors by torquing alternately in increments of $0.2T_{inst}$. After each increment, inspect the concrete surface for cracks. Stop the test when concrete splitting or anchor material failure prevents the torque from being increased further. For each test, record the maximum torque. 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.

8.1.3.2 For load-controlled undercut anchors, screw anchors, and adhesive anchors, install the anchors according to the manufacturer's installation instructions and load the group of two anchors in tension to failure.

8.1.3.3 For displacement-controlled anchors and undercut anchors that are intended to perform properly without an installation torque, install the anchors according to the manufacturer's installation instructions and load the group of two anchors in tension to failure.

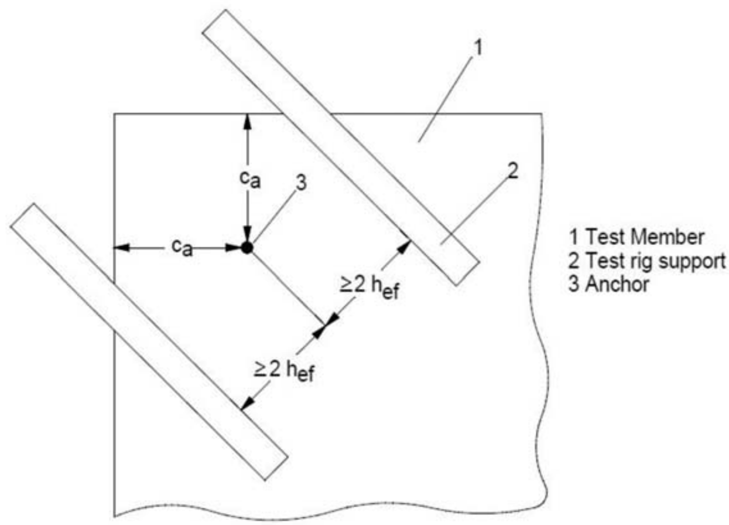


FIG. 8 Example of Test Setup for Corner Splitting Test

8.2 *Tension Load Tests in Cracked Concrete:*

8.2.1 *Tests in a Static Crack*—Perform the test according to 8.1.1, except that for anchors evaluated for use in cracked concrete, tension tests shall be permitted to be performed in cracked concrete with a crack width w.

8.2.2 *Tests in Cracked Concrete Where Crack-Width is Cycled*—Table 5 gives the parameters to be used for the crack-width cycling test unless otherwise specified. Before installing the anchor, crack opening and closing cycles n_{pt} shall be permitted to be applied to stabilize crack formation. Install the anchor according to 7.1 so that the axis of the anchor lies approximately in the plane of the crack. After the anchor is installed, widen the crack by a width w_1. Apply a sustained tensile load of N_w. Cycle the crack width between the maximum crack opening width of w_1 and the initial minimum crack width of w_3.

NOTE 3—w_1 is additive to any widening resulting from the anchor installation.

TABLE 5 Parameters for Crack-Width Cycling Test

Parameter	Symbol	Value[A]
Permitted pretest crack cycles	n_{pt}	10
No. of test cycles	n_{ct}	1000
Frequency of crack width cycles	–	≤0.2 Hz
Largest crack width during test	w_1	≥0.012 in. [0.3 mm]
Smallest crack width during test	w_2	≥0.005 in. [0.1 mm]
Smallest crack width at beginning of test	w_3	0.004 in. [0.1 mm]
Smallest value of $w_1 - w_2$		0.004 in. [0.1 mm]
Static load during test	N_w	$N_w = 0.3N_{p,cr}\sqrt{\frac{f_{c,test}}{f'_c}}$

[A] Recommended value, unless otherwise established by other criteria.

As the crack width is varied cyclically, keep N_w constant within a tolerance of ±5 %. Open and close the crack n_{ct} times at the specified frequency, keeping the crack width w_1 constant. Due to the design of the anchor being tested, the crack width w_2 is permitted to increase without external control during the test from its initial value of w_3 (see Fig. 9). The difference between the greatest and smallest crack widths during each cycle (opening and closing cycles) shall be at least $w_1 - w_2$. If at any time during the test the value of $w_1 - w_2$ falls below a minimum specified value, increase the upper-bound value of the crack inducing load until the minimum value of $w_1 - w_2$ is restored.

8.2.2.1 Measure the load-displacement relationship up to load N_w. Afterward, under N_w, measure the displacements of the anchor and the crack-opening widths w_1 and w_2 as specified.

8.2.2.2 After completing the cycles of crack opening and closing, unload the anchor, measure the residual displacement, and perform a tension test to failure with a specified crack width w_1 at the start of the tension test.

8.3 *Shear Capacity Tests in Uncracked Concrete:*

8.3.1 *Tests for Single Anchor Without Edge and Spacing Effects*—Position the loading system so that the placement of the test system supports meets the requirements of Table 1 (see Fig. 4). A reaction bridge is not required along the edge of the test member where concrete breakout in shear does not limit the shear resistance.

8.3.2 Position and fasten the test member in the support system so that the test surface of the test member is parallel to the loading plate and the axis of the loading rod. Place the loading plate-rod assembly onto the test member and secure it in place with the appropriate nut or other locking device typically used for the particular anchor installation to be tested. The amount of force exerted on the loading plate by the attaching nut or locking device shall be uniform for each series of tests performed.

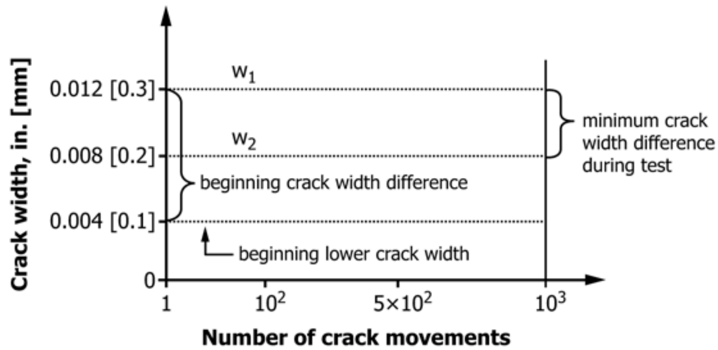


FIG. 9 Crack-width Requirements for Crack Cycling

8.4 *Shear Capacity in Cracked Concrete*—Perform the test according to 8.3, except that for anchors evaluated for use in cracked concrete, shear tests shall be permitted to be performed in cracked concrete with a crack width *w* with the load applied parallel to the crack.

9. Dynamic Load Tests

9.1 *Repeated Load Test*—Subject the anchor to a pulsating tensile load that varies sinusoidally between specified maximum and minimum loads. The loading frequency and number of loading cycles shall be as specified. Measure anchor displacement continuously or up to the maximum load during the first loading, and then at specified intervals up to the maximum number of intervals. At the end of the cyclic loading, test the anchor in tension to failure.

9.2 *Simulated Seismic Tension Tests*—Perform these tests in cracks when specified. Install the anchor in a closed crack in accordance with 7.1 and 7.5.1. Test internally threaded anchors with the bolt as specified by the manufacturer. Open the crack by the specified amount in addition to the initial hairline crack width. Apply the sinusoidal tension loading sequence at the specified frequency. Record the crack width, anchor displacement, and applied tension load in accordance with 7.5.

9.2.1 After 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) and the corresponding displacement, and plot the load-displacement curve.

9.3 *Simulated Seismic Shear Tests*—Perform tests in cracks when specified. Install each anchor in a closed crack in accordance with 7.1 and 7.5.1. Test internally threaded anchors with a bolt as specified by the manufacturer. Open the crack by the specified amount in addition to the initial hairline crack width. Subject the anchors to the specified sinusoidal shear loading sequence, applied parallel to the direction of the crack.

The frequency of loading shall be specified. 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. 10. Record the crack width, anchor displacement and applied shear load in accordance with 7.5. Plot the load-displacement history in the form of hysteretic loops.

After 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 curve.

9.4 *Fatigue Tests:*

9.4.1 *Equipment*—Any testing machine as described in the Apparatus section shall be permitted to be used, provided the requirements of specific loading rate and accuracy are met. The test equipment shall not produce resonant vibrations during the tests.

9.4.2 *Number of Test Specimens*—Base the number of test specimens on the purpose of the test. If the objective is to

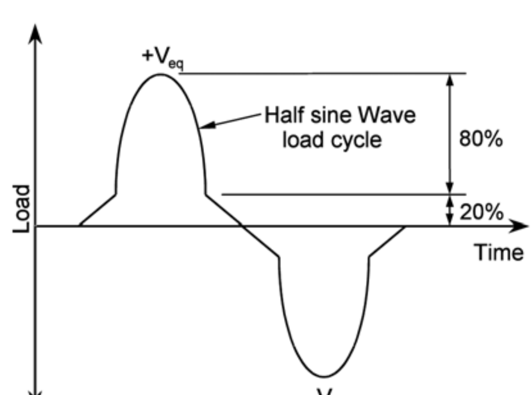


FIG. 10 Permitted Approximation of Simulated Seismic Shear Cycle

obtain runout at or below the endurance limit (that is, 2×10^6 cycles) at a given load, three samples that reach runout are sufficient. If the test objective is to determine the endurance limit (maximum load that will reach runout), then perform tests in accordance with Practice E468.

9.4.3 *Fatigue Test Procedure*—Apply the specified fatigue test program, including the method, load levels, frequency, and number of cycles.

9.4.4 Once the cyclic test has been completed, apply a static tension load in accordance with the section on Static Tests to determine its residual strength and failure mode in accordance with the section on Failure Criteria.

9.5 *Shock Test:*

9.5.1 *Equipment*—This test method is not intended to prohibit the use of any testing or loading device which provides the performance described in the Apparatus section.

9.5.2 *Number of Test Specimens*—The purpose and type of the shock test determines the required number of test specimens.

9.5.2.1 If the purpose is to determine if an anchor will withstand a specified shock load (magnitude and duration), test at least three replicates of each anchor diameter at a particular load magnitude and duration.

9.5.2.2 If the purpose is to determine the maximum shock loading an anchor can withstand without failure, use a suitable test method (such as a staircase method) to obtain anchor failure. Three separate anchor tests at a given load without failure shall be sufficient to establish the maximum shock capacity of the anchorage system.

9.5.3 *Shock Test Procedure:*

9.5.3.1 *Tension Test*—Position the loading system as described in 8.1.1.1.

9.5.3.2 *Shear Test*—Position the loading system as described in 8.3.1.

9.5.4 *Rate of Loading Tension or Shear*—Apply a specified number of shocks to each anchor in a triangular (ramp) loading rate with a duration of 30 ms per shock, or as otherwise specified. After application of the shock loads, test the anchors in tension in accordance with the Static Tests section to measure residual static tensile capacity, if required.

10. Torque Tests

10.1 *General Test Conditions*—Fig. 11 shows the essential elements of the typical test setup. The double-sided abrasive paper or equivalent 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 they do not affect the performance of the anchor. 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.

11. Environmental Effects Tests for Adhesive Anchors

11.1 *Sensitivity to Hole Cleaning (Reduced Cleaning Effort)*—These tests are performed to quantify the performance of adhesive anchors installed in adverse conditions.

11.1.1 *Sensitivity to Hole Cleaning, Dry Substrate:*

11.1.1.1 This test presumes a method of hole cleaning that includes blowing out the hole with air and cleaning the wall of the hole with a brush. Other methods are acceptable; however, the manufacture's installation instructions for the product shall contain sufficient detail to permit the determination of a numeric reduction of the cleaning effort. For hole cleaning methods that involve blowing and brushing operations, sufficient detail is defined as:

(1) Requirements for all equipment to be used in the process, including air/vacuum pressure, assembly of nozzle and associated components as required, and brush materials and dimensions.

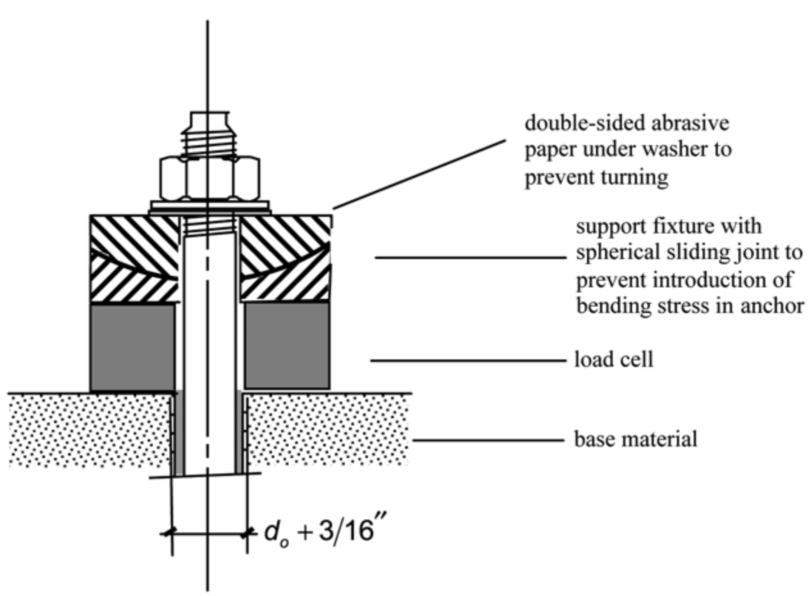


FIG. 11 Example of Torque Test Setup

(2) Acceptable methods and minimum number and duration of the operations required for removal of drilling dust from the hole (blowing).

(3) Acceptable methods and minimum number and duration of the operations required for removal of drilling dust from the wall of the hole (brushing).

(4) The required sequence of operations.

11.1.1.2 Drill the hole downwards to the depth determined by the manufacturer. Unless otherwise specified, clean the hole using only 50 % of the specified minimum number of operations defined in 11.1.1.1, rounding down to the next whole number of operations. Do not modify the sequence of operations defined in 11.1.1.1. Install anchors in accordance with 7.1. Conduct confined tension test in accordance with 5.4.2 and 8.1.1.

11.1.2 *Sensitivity to Hole Cleaning with Installation in Water-Saturated Concrete:*

11.1.2.1 *For Holes Drilled with a Carbide Drill Bit*—Drill a pilot hole downwards to the specified depth with a bit approximately half the diameter of the specified hole diameter. Remove the drilling dust from the hole. Fill the pilot hole with tap water and ensure that the hole remains flooded for a minimum of 8 days (192 h). Immediately prior to installing the anchor, remove all freestanding water with a vacuum and re-drill the hole with the specified drill bit diameter. Clean the hole in accordance with 11.1.1.2. Install anchors in accordance with 7.1. Conduct confined tension test in accordance with 5.4.2 and 8.1.1.

11.1.2.2 *For Water-Flushed Holes*—Prepare and clean the hole in accordance with 11.1.2.1; however, if the manufacturers installation instructions specify flushing of the hole with water prior to anchor installation, flush the hole in accordance with the manufacturer's recommendations. Immediately prior to anchor installation, remove all freestanding water with a vacuum. Install anchors in accordance with 7.1. Conduct confined tension test in accordance with 5.4.2 and 8.1.1.

11.1.3 *Sensitivity to Hole Cleaning with Installation in Water-Filled Hole in Saturated Concrete:*

11.1.3.1 *For Holes Drilled with a Carbide Drill Bit*—Prepare and clean the hole in accordance with 11.1.2.1; however, re-fill the hole with tap water immediately prior to anchor installation. Install anchors in accordance with 7.1. Conduct confined tension test in accordance with 5.4.2 and 8.1.1.

11.1.3.2 *For Water-Flushed Holes*—Prepare and clean the hole in accordance with 11.1.2.2; however, re-fill the hole with tap water immediately prior to anchor installation. Install anchors in accordance with 7.1. Conduct confined tension test in accordance with 5.4.2 and 8.1.1.

11.1.4 *Sensitivity to Hole Cleaning with Installation in Submerged Concrete:*

11.1.4.1 Drill a pilot hole downwards to the specified depth with a bit approximately half the diameter of the specified hole diameter. Remove the drilling dust from the hole. Fill the pilot hole with tap water and ensure that the hole remains flooded for a minimum of 8 days (192 h). Cover the upper surface of the water-saturated concrete test member with tap water to a minimum depth of ½ in. [12 mm]. This depth of coverage is to be maintained for the duration of the test, including hole drilling, anchor installation and testing. Re-drill the hole in the submerged concrete with the specified drill bit diameter. Clean the hole in accordance with 11.1.1.2. Install anchors in accordance with 7.1. Conduct confined tension test in accordance with 5.4.2 and 8.1.1.

11.2 *Sensitivity to Installation in Water-Saturated Concrete*—Perform the test in accordance with 11.1.2; however, hole cleaning shall be conducted in accordance with the manufacturer's installation instructions for the product. Install anchors in accordance with 7.1. Conduct confined tension test in accordance with 5.4.2 and 8.1.1.

11.3 *Sensitivity to Installation in Water-Filled Hole in Saturated Concrete*—Perform the test in accordance with 11.1.3; however, hole cleaning shall be conducted in accordance with the manufacturer's published installation instructions for the product. Install anchors in accordance with 7.1. Conduct confined tension test in accordance with 5.4.2 and 8.1.1.

11.4 *Sensitivity to Installation in Submerged Concrete*—Perform the test in accordance with 11.1.4; however, hole cleaning shall be conducted in accordance with the manufacturer's installation instructions for the product. Install anchors in accordance with 7.1. Conduct confined tension test in accordance with 5.4.2 and 8.1.1.

11.5 *Sensitivity to Freezing and Thawing:*

11.5.1 *General Test Conditions*—Perform sustained tension tests in uncracked concrete, followed by confined tension tests to failure.

11.5.2 The test member shall consist of a cube or cylinder with side length (or diameter) 8 in. $\le \ell_{side} \le$ 12 in. [200 mm $\le \ell_{side} \le$ 300 mm] for anchor diameters ½ to ⅝ in. [12 to 16 mm]. For anchor diameters d greater than ⅝-in. [16 mm], the test member shall have side length $15d \le \ell_{side} \le 25d$. The dimensions of the test member shall be chosen to avoid splitting of the test member during the conduct of the test. Freezing and thawing 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 (for example, steel cylinder), the dimensions of the specimen may be reduced.

11.5.3 Install and cure anchors at standard temperature.

11.5.4 Cover the top surface of the test member with tap water within a radius of at least 3 in. [76 mm] from the center of the test anchor. Maintain a minimum of ½ in. [12 mm] depth throughout the test. Seal all other exposed surfaces of the test member to prevent evaporation of water. Load the anchor with a specified constant tension load $N_{sust,ft}$.

11.5.5 Carry out specified number of freezing and thawing cycles as follows:

11.5.5.1 Maintain load at $N_{sust,ft}$ throughout the freezing and thawing test.

11.5.5.2 Raise the temperature of the chamber within 1 h to +68°F ± 5°F [+20°C ± 2°C].

11.5.5.3 Maintain the chamber at +68°F ± 5°F [+20°C ± 2°C] for an additional 7 h.

11.5.5.4 Lower the temperature of the chamber to –4°F ± 5°F [–20°C ± 2°C] within 2 h.

11.5.5.5 Maintain the chamber temperature at –4°F ± 5°F [–20°C ± 2°C] for an additional 14 h.

11.5.6 Measure the displacements during the temperature cycles.

11.5.7 If the test is interrupted, store the samples at a temperature of –4°F ± 5°F [–20°C ± 2°C] between cycles.

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

11.6 *Sensitivity to Sustained Load:*

11.6.1 *General:*

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

11.6.1.2 Install and cure anchors at standard temperature, unless otherwise specified.

11.6.1.3 Conduct tests at the target temperature defined by the criteria or manufacturer.

11.6.1.4 Temperature control shall be maintained via thermocouples in the concrete test member. Embed thermocouples at a maximum of 4½ in. [115 mm] from the surface of the concrete into which the anchors are to be installed. The thermocouples shall be 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 ½ in. [12 mm] and shall be sealed in such a manner that the temperature readings reflect the concrete temperature.

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

11.6.2 *Sustained Load Test:*

11.6.2.1 Within 48 h of when the curing period has elapsed, the temperature of the test member shall be adjusted until the temperature as recorded by the thermocouples is stabilized at the target temperature. A tension preload not exceeding the lesser of 5 % of the specified sustained tension load or 300 lb [1334 N] shall be applied to the anchor prior to zeroing displacement readings. After zeroing the displacement readings, increase the load on the anchor to the specified sustained tension load.

11.6.2.2 Maintain not less than minimum specified sustained tension load and maintain the temperature at the target temperature for the duration of the test.

11.6.2.3 Anchor displacement shall be recorded for the duration of the test. As displacements are typically greatest in the early stages, the minimum monitoring schedule shall be as follows:

(1) During the first hour: Every 10 min.

(2) During the next 6 h: Every hour.

(3) During the next 10 days: Every day.

(4) Thereafter: Every 5 to 10 days.

11.6.2.4 Temperatures in the test chamber shall be permitted to vary by ±6°F [±3°C] due to daily and seasonal effects, but the required 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.

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

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

11.6.2.6 At the conclusion of the sustained loading portion of the test, remove the sustained load and conduct a confined tension test in accordance with 5.4.2 and 8.1.1.

11.7 *Tension Tests with Decreased Installation Temperature:*

11.7.1 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]. Perform tests as follows:

11.7.1.1 Prior to installation, condition the anchor rod and test member to the target temperature (that is, the lowest installation temperature recommended by the manufacturer) and maintain that temperature for a minimum of 24 h.

11.7.1.2 Install the anchors in concrete test members and allow them to cure at the stabilized temperature for the curing time specified in the manufacturer's printed installation instructions.

11.7.1.3 Immediately thereafter, remove the test members from the cooling chamber and test them in tension making sure that they remain at the conditioned temperature. A thermocouple inserted into the test member may be used to confirm the temperature at the time of testing.

11.7.2 When anchors are recommended for installation in concrete temperatures below 40°F [5°C], in addition to the tests described in 11.7.1, install and test at least five anchors as follows:

11.7.2.1 Prior to installation, condition the anchor rod and test member to the target temperature (that is, the lowest installation temperature recommended by the manufacturer) and maintain that temperature for a minimum of 24 h.

11.7.2.2 Install the anchors in accordance with the manufacturer's printed installation instructions and allow them to cure at the stabilized target temperature for the curing time specified in the manufacturer's printed installation instructions.

11.7.2.3 Immediately thereafter, apply a constant tension load $N_{sust\,ft}$.

11.7.2.4 Raise the temperature of the test chamber at a constant rate to standard temperature over a period of 72 to 96 h 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.

11.7.2.5 Once the test member attains standard temperature, conduct a confined tension test to failure with continuous measurement of load and displacement.

11.8 *Punch Tests to Evaluate Environmental Effects—*

11.8.1 *General Test Conditions*—Conduct tests on ½ in. [12 mm] diameter all-thread anchors or the smallest nominal diameter if that diameter is larger than ½ in. [12 mm]. Embed anchors into cylindrical concrete test members with a minimum diameter of 6 in. [150 mm]. 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 installation instructions. The anchor material shall be fabricated from non-reactive 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 ± 1⁄8 in. [30 ± 3 mm] thick slices so that the resulting slices are not damaged. The slices shall be oriented perpendicular to the anchor axis and shall consist of the concrete, adhesive material and anchor element. Discard the top and bottom slices. Prepare at least ten slices for each environmental exposure to be investigated as well as ten reference slices to be subjected to standard climate conditions.

11.8.1.1 *Storage of Reference Slices*—Store the slices under normal climate conditions (standard temperature and relative humidity 50 ± 5 %) for the specified time.

11.8.1.2 *Storage of Slices Under Aggressive Environmental Exposure*—Store the slices under the specified aggressive environmental exposures for the specified time.

11.8.2 *Punch Tests*—After the storage time has elapsed allow the slices from 11.8.1.2 to fully dry before testing. Measure their thickness and test them in an apparatus that punches the metal element of the slice through the slice while restraining the surrounding concrete (see Fig. 12). The loading punch shall act centrally on the metal element. Record the peak load for each test. Discard the results from slices that split during the punch test.

12. Screw Anchor Tests

12.1 *Setting of Screw Anchors:*

12.1.1 Permitted setting methods for screw anchors shall be defined by the manufacturer. For those systems that are to be set with a torque wrench, the installation torque T_{screw} shall be specified. For those systems set with a machine (impact screw driver, other), the type of machine and maximum power output rating shall be specified. Alternately, the characteristics of acceptable machines in terms of power output shall be specified.

12.1.2 Unless otherwise specified install the screw anchor until the head just contacts the fixture and the fixture can no longer be moved by hand.

12.1.3 For those systems that may be set with either a specified installation torque or with a machine, the anchors shall be set with a torque wrench and the specified installation torque T_{screw} shall not be exceeded. If upon the application of the specified installation torque the fixture remains loose, the specified installation torque T_{screw} shall either be re-established at a higher level until this condition is satisfied or the anchor shall be deemed unsuitable. For those systems set with a range of machines that satisfy a maximum power output rating specified by the manufacturer, an impact screw driver with maximum power output specified in the manufacturer's installation instructions for the anchor size shall be used. The test laboratory shall select the screw driver with maximum power output for this application from the screw drivers on the market fulfilling the specifications of the anchor manufacturer. Following installation of the anchor in accordance with the manufacturer's published installation instructions, the fixture shall be checked by hand to determine that it is not loose.

12.2 *Tension Test Under Repeated Load:*

12.2.1 *Installation*—Install the screw anchor in accordance with 12.1 and the following. Set the screw anchor on an beveled washer (inclination angle greater than or equal to 4°, hardness greater than or equal to HRC 32, fixture hole oversize less than or equal to 1⁄8 in. [3 mm]). The point of maximum dimension of the head shall contact the beveled washer. In cases where the product geometry includes a fillet under the anchor head or where the head is countersunk, the bevel washer shall be modified such that the fillet shall not be in contact with the bevel washer. The position is shown in Fig. 13 Following anchor installation, the screw anchor head shall be permitted to either partially contact the beveled washer (see Fig. 14(*a*)) or in full contact against the washer (seeFig. 14(*b*)). Any position of the anchor head within and including the extreme positions shown in Fig. 14 shall be acceptable.

12.2.1.1 The core hardness of the test specimens shall be established by testing the core hardness at mid length of the specified number of screws from the same manufacturing lot, heat treated at the same time as the screw specimens to be tested. Test in accordance with Test Methods F606/F606M as applicable.

12.2.2 Test the screw anchors in accordance with 9.1.

12.3 *Test of Screw Anchors for Brittle Failure:*

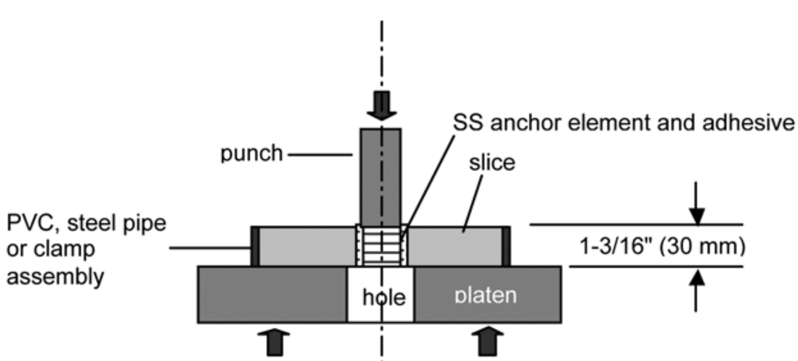


FIG. 12 Punch Test

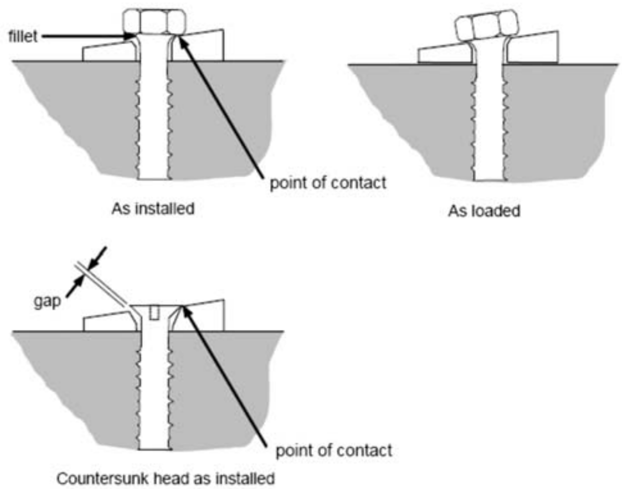
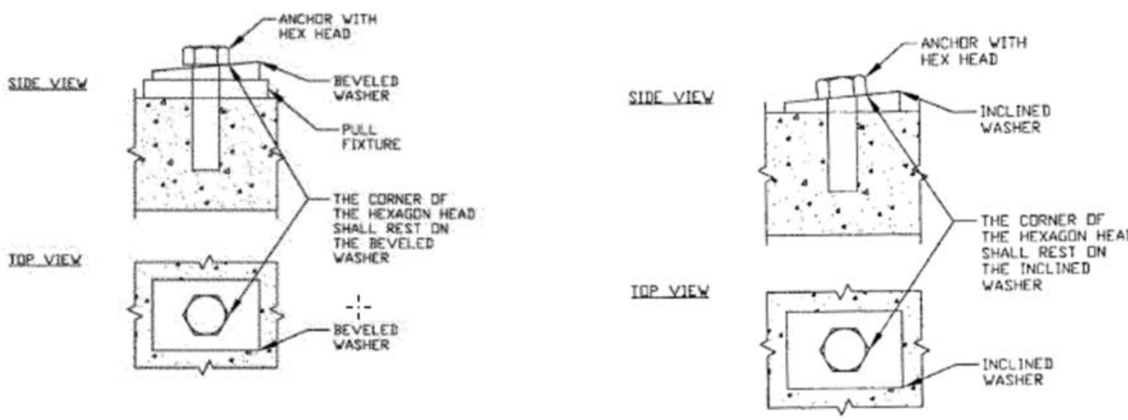


FIG. 13 Bevel Washer Geometry for Different Head Shapes



a) Anchor just contacting bevel washer

b) Anchor fully prestressed against bevel washer

FIG. 14 Acceptable Position of the Anchor Head in Tests with Repeated Loads

12.3.1 These tests are intended to verify sufficient insensitivity to stress-induced hydrogen embrittlement cracking under conditions as may occur in service.

12.3.2 Test specimens shall have a core hardness equal to the upper limit of the specified hardness range, with a tolerance of +0/–2 HRC.

12.3.3 *Test Method A (Confined Test):*

12.3.3.1 Perform five tests on all diameters from each manufacturing process, material, coating, and design. Tests shall be conducted at shallow (min h_{nom}) and deep embedments (max h_{nom}) per diameter. For concrete screws with different head forms, anchors with the most adverse head form shall be tested. If the most adverse head form cannot be readily identified, tests with different head forms shall be performed. Concrete screws shall be installed in an uncracked high strength concrete specimen having a minimum compressive strength of 7500 psi [51.7 MPa] in accordance with the manufacturer's instructions. Where steel failure occurs in the reference tests, the concrete strength corresponding to those tests shall be permitted to be used.

12.3.3.2 The borehole shall be drilled with a medium drill bit diameter d_m. The concrete specimen shall be chosen large enough to preclude splitting failure. Alternatively, the specimen can be cast in a steel ring. Only one test per concrete specimen shall be performed at a time unless a concrete specimen is used that can accommodate more than one anchor. At the concrete screw location, a bottomless container covering an area of at least 15 in.^{2} [9677 mm^2]with a height of at least 1 in. [25.4 mm] shall be affixed to the concrete and filled with a saturated calcium hydroxide solution [$Ca(OH)_2$] having a pH = 12.6 ± 0.1 measured at 77°F ± 2°F [25°C ± 1°C]. During the test the head of the concrete screw shall be submerged in the fluid. The temperature during the test shall be maintained at 77°F ± 9°F [23°C ± 5°C]. Furthermore the pH-value shall be kept constant by measuring the pH value after 5 days. If the pH-value exceeds the tolerance value (as might occur due to interaction with the concrete) the solution shall be replaced. The material of the counter electrode shall be stainless steel or activated titanium. The reference electrode is defined by its composition. Its accuracy should be controlled by calibration with a new electrode (tolerance ±20 mV). The tip of the reference electrode should be located at a distance equal to approximately $0.5h_{nom}$ (see Fig. 15) from the concrete surface. This can be achieved by a bore hole depth equal to approximately $0.5h_{nom}$. The length of the counter electrode should be equal to approximately h_{nom}. Reference and counter electrode shall be placed in drilled holes with a diameter of approximately 1⁄16 in. [1.5 mm] larger than the diameter of the electrode. The reference electrode should be located as close as possible to the concrete screw and not farther away than 6 in. [150 mm]. The distance between reference electrode and counter electrode shall not exceed 2 in. [50 mm]. Before testing, coatings of any kind shall be partially removed in shape of a longitudinal strip to allow hydrogen evolution on the steel surface. The concrete screw shall be subjected to a constant tension load $N_{sust,con} = \min\{0.7N_{u,con,mean}, 0.5N_{st,mean}\}$ over a period of minimum 240 h. $N_{u,con,mean}$ is the average ultimate tensile load of the confined reference tests, multiplied by:

$$\sqrt{\frac{f'_{c,test}}{f'_{c,ref}}}$$

During the duration of the test, a constant electrochemical potential shall be established and shall be held constant with potentiostatic control or by other appropriate means at –1200 mV ± 20 mV (SCE) measured against a saturated calomel electrode (SCE). An acceptable test setup is shown in Fig. 16. Other types of electrodes (for example, Ag/AgCl) may be used with appropriate correction of the potential. Following the constant load portion of the test, unload the concrete screw anchor and perform a confined tension test to failure in accordance with 5.4.2 and 8.1.1.

12.3.4 *Alternate Test Method A (Unconfined Test)*—In the Alternate Test Method A, the test shall be performed as unconfined test with a beveled washer under the anchor head (see Fig. 17). Perform 5 tests on all diameters from each manufacturing process, material, coating, and design. Tests shall be conducted at shallow (min h_{nom}) and deep embedments (max h_{nom}) per diameter. For concrete screws with different head forms, anchors with the most adverse head form shall be tested. If the most adverse head form cannot be readily identified, tests with different head forms shall be performed. Concrete screws shall be installed in an uncracked high strength concrete specimen having a minimum compressive strength of 7500 psi [51.7 MPa] in accordance with the manufacturer's instructions. Where steel failure occurs in the reference tests, the concrete strength corresponding to those tests may be used.

12.3.4.1 The borehole shall be drilled with a medium drill bit diameter d_m. The concrete specimen shall be chosen large enough to preclude splitting failure. Alternatively, the specimen may be cast in a steel ring. Only one test per concrete specimen shall be performed at a time unless a concrete specimen is used that can accommodate more than one anchor. The screw anchor shall be set on a beveled washer [inclination angle ≥4°, hardness ≥HRC 32, fixture hole oversize ≤1⁄8 in. [3.2 mm]]. The point of maximum dimension of the head shall contact the beveled washer. The position is shown in Fig. 14. Following anchor installation, the screw anchor head may either partially contact the beveled washer (see Fig. 14(*a*)) or be in full contact against the washer (see Fig. 14(*b*)). Any position of the anchor head within and including the extreme positions shown in Fig. 13 shall be acceptable. For screws with fillets under the head or where the head is a countersunk configuration, see 12.3. At the concrete screw location, a bottomless container covering an area of at least 15 in.^{2} [9677 mm^2]with a height of at least 1 in. [25.4 mm] shall be affixed to the concrete and filled with a saturated calcium hydroxide solution $Ca(OH)_2$ having a pH = 12.6 ± 0.1 measured at 77°F ± 2°F [25°C ± 1°C]. During the test the head of the concrete screw shall be submerged in the fluid. The temperature during the test shall be maintained at 77°F ± 9°F [25°C ± 5°C]. Furthermore, the pH-value shall be kept constant by measuring the pH value after 5 days. If the pH-value exceeds the tolerance value (as might occur due to interaction with the concrete) the solution shall be replaced. The material of the counter electrode shall be stainless steel or activated

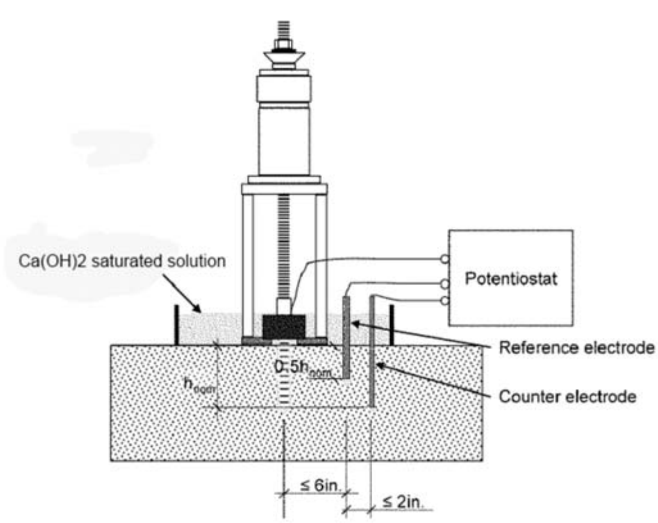


FIG. 15 Example of Confined Test Setup for Checking Brittleness of Concrete Screws (Test Method A)

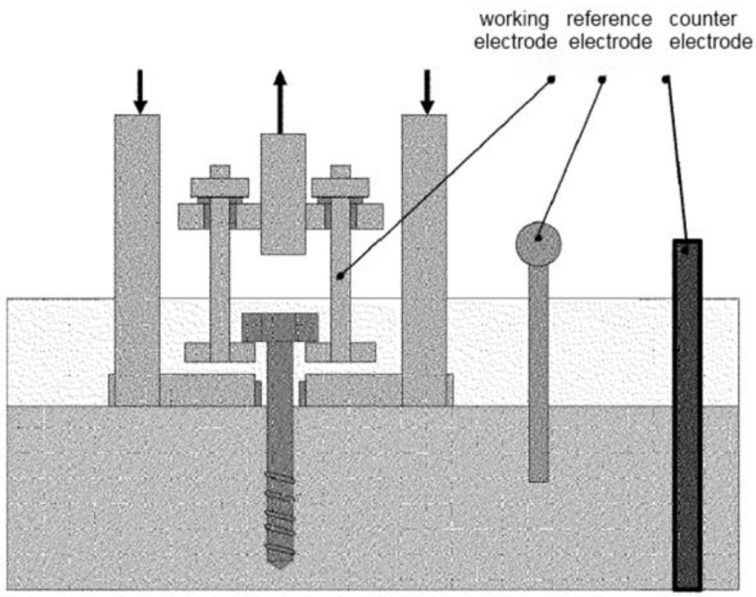


FIG. 16 Details of Attachment for Anchor During Test for Brittleness of Concrete Screws (Test Method A)

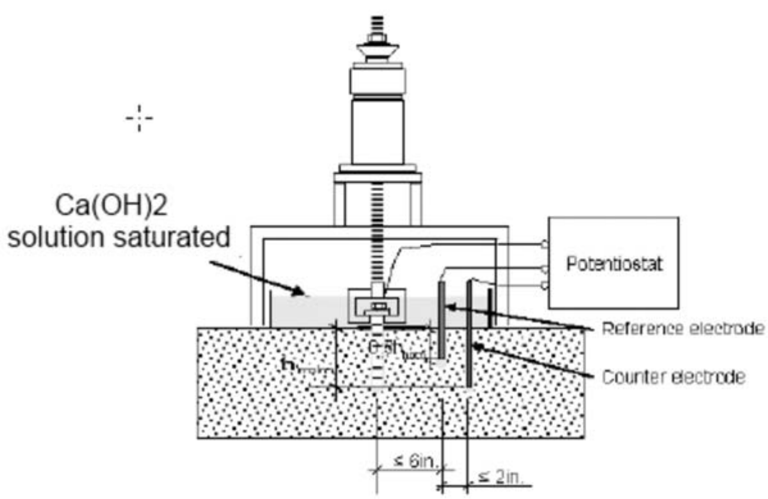


FIG. 17 Example of Unconfined Test Setup with Bevel Washer Under Anchor Head for Checking Brittleness of Concrete Screws (Alternate Test Method A)

titanium. The reference electrode is defined by its composition. Its accuracy should be controlled by calibration with a new electrode (tolerance ±20 mV). The tip of the reference electrode should be located at a distance equal to approximately $0.5h_{nom}$ (see Fig. 17) from the concrete surface. This can be achieved by a bore hole depth equal to approximately $0.5h_{nom}$. The length of the counter electrode should be equal to approximately h_{nom}. Reference and counter electrodes shall be placed in drilled holes with a diameter of approximately 1⁄16 in. [1.5 mm]) larger than the diameter of the electrode. The reference electrode should be located as close as possible to the concrete screw and not farther away than 6 in. [150 mm]. The distance between reference electrode and counter electrode shall not exceed 2 in. [50 mm]. Before testing, coatings of any kind shall be partially removed in shape of a longitudinal strip to allow hydrogen evolution on the steel surface. The concrete screw shall be subjected to a constant tension load $N_{sust,\ell} = \min\{0.7N_{u,mean}; 0.5N_{st,mean}\}$ over a period of 100 h minimum. $N_{u,mean}$ is the average ultimate tensile load from reference tests multiplied by:

$$\sqrt{\frac{f'_{c,test}}{f'_{c,ref}}}$$

During the duration of the test, a constant electrochemical potential shall be established and shall be held constant with potentiostatic control or by other appropriate means at –1200 mV ± 20 mV (SCE) measured against a saturated calomel electrode (SCE). Other types of electrodes (for example, Ag/AgCl) may be used with appropriate correction of the potential. A suggested test setup is shown in Fig. 16. Following the constant load portion of the test, unload the concrete screw anchor and perform a confined tension test to failure in accordance with 5.4.2 and 8.1.1.

12.3.5 *Test Method B:*

12.3.5.1 This test method applies to concrete screw anchors that can be loaded in tension or bending during installation and in service. This test method is limited to evaluating hydrogen induced embrittlement due to processing (IHE) and environmental exposure (EHE). This test method is limited to ferrous fasteners that are susceptible to time-delayed fracture caused by the diffusion of hydrogen under stress. A four-point bend specimen undergoes sustained load and slow strain rate testing by using incremental loads and hold times under displacement control to measure a threshold stress in an accelerated manner in accordance with Test Method F1624. The test is an accelerated incrementally increasing step load test method that measures the threshold for hydrogen stress cracking.

12.3.5.2 *Referenced Documents—*Referenced documents are those contained in the Referenced Documents section of Test Method F1624.

12.3.5.3 *Terminology:*

core threshold, n—the maximum load at the onset of cracking of the core that is identified by a 5 % drop in load under displacement control where the test specimen does not continue to maintain the test load to the next two step load levels.

environmental hydrogen embrittlement (EHE), n—environment embrittlement caused by hydrogen introduced into steel from external sources.

FFS(B), n—fast fracture strength in air of a fastener specimen in bending determined in accordance with Test Methods E8/E8M.

internal hydrogen embrittlement (IHE), n—embrittlement caused by residual hydrogen from processing

process, n—a defined event or sequence of events that may include pretreatments, plating, or coating and post treatments that are being evaluated or qualified.

12.3.5.4 *Test Specimens—*The test specimens shall be selected by the testing laboratory and shall be representative of the production fasteners as to base metal, diameter, thread configuration, coating and hardness profile. Test specimens shall have a core hardness equal to the upper limit of the specified hardness range with a tolerance of +0/–2 HRC. A separate series of tests under Test Method B are not required for different fastener lengths having the same base metal, diameters, thread configurations, coating, and hardness profiles.

Specimens shall be ultrasonically cleaned in acetone for 5 to 10 min to remove any contaminants such as oils and dirt. Acid cleaning shall not be allowed.

Test specimens shall be cut from the randomly selected samples as shown in Fig. 18 and such specimens shall be of sufficient length for proper insertion into the gripping devices to achieve the selected four point bending. See Fig. 19 for an example of a gripping device to achieve the selected four point bending. The cut sample to be tested shall include the portion of the fastener with uniform screw thread configuration but shall exclude the non-threaded portion of the fastener and any case hardened induction zones at the end of the fastener. Before testing, test specimens obtained from fasteners with coatings of any kind shall have the coating removed in the shape of a longitudinal strip and be positioned on the tensile side of the test specimen. The above coating removal shall occur within the space of the minimum two threads as shown in Fig. 19.

12.3.5.5 *Summary of Test Method:*

(1) Specimens shall be tested in the hydrogen embrittling environmental conditions specified in Test Method F1624 using the step load procedure in the Procedure section of Test Method F1624, except as modified herein. A minimum of three tests are required as follows:

1. First test is a 20/5/1 (twenty steps in five percent increments with a 1-h hold for each step).

2. Second test is a 10/5/2 (first ten steps of the test), followed by a 10/5/4 (second ten steps of the test). Loading is not released during the transition from the 2-h to 4-h hold requirement.

3. Third test is a repeat of the second test.

If an invariant value within 5 % is obtained in two consecutive tests as a result of the completion of the three minimum required tests, no further tests are required. Otherwise, additional tests at longer hold times shall be performed until an invariant value within 5 % is obtained in two consecutive tests. The loading rate shall be slow enough to ensure that a core threshold will be detected if deleterious amounts of hydrogen are present in "worst case" scenario. The load used for determination of the value of each of the steps (that is, loads divided by the number of steps) for the first test shall be based on the average value of tensile strength resulting from the three bending (FFS(B)) tests in air based upon the minimum diameter cross-section of the fasteners. The load used for determination of the value of each of the steps (that is, load divided by the number of steps) for each of the subsequent tests shall be 110 % of the core threshold value determined in the previous test but not more than the load used to establish the

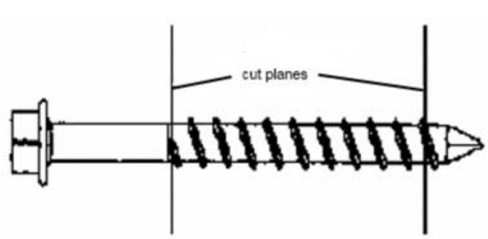


FIG. 18 Illustration of Test Specimen Extraction

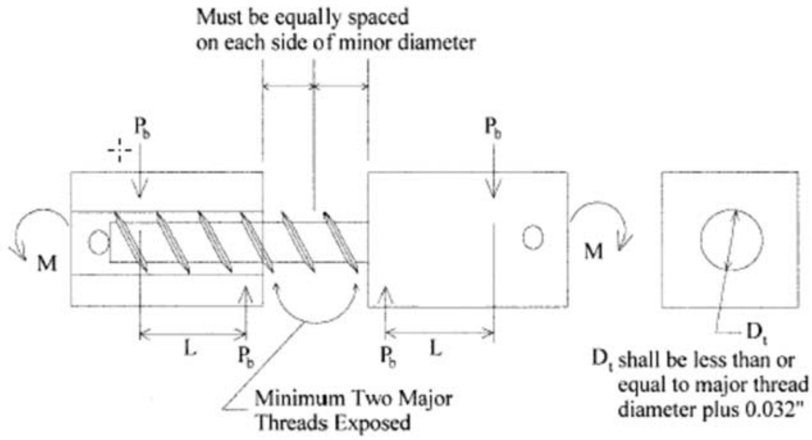


FIG. 19 Example of Four-Point Gripping Device

steps in the previous test. The lowest core threshold value established by the two consecutive tests used to meet the invariant value requirement from the hydrogen embrittling environmental conditions test shall be autographically recorded in terms of load versus time and included as part of the report.

(2) Apparatus.

(3) Testing Equipment—Testing equipment shall be within the guidelines of calibration, force range, resolution, and verification of Practices E4.

(4) Gripping Devices—Various types of gripping devices may be used for the four-point bending to transmit the measured load applied by the testing equipment to the test specimen. Fig. 19 illustrates an example of a four-point gripping device.

(5) Test Environment —The test shall be conducted in an aggressive hydrogen producing environment by imposing a cathodic galvanic potential in salt water contained in an appropriate inert container.

(6) Poteniostatic Control—The corrosion potential of the specimen shall be controlled with a reference Saturated Calomel Electrode (SCE) or equivalent reference electrode such as Ag/AgCl in accordance with Test Method G5. The imposed potential is cathodic and shall be set at –1.2 ± 0.025 V versus SCE (VscE) in a 3.5 weight percent NaCl solution.

(7) Calculations—Calculations shall be in conformance with the Calculations section of Test Method F1624.

(8) Report—A test report shall be produced in accordance with the Report section of Test Method F1624 and shall include the audiographic recordings specified in Test Method F1624.

13. Other Tests

13.1 *Tests for Anchors Installed Through the Soffit of Concrete-Filled Metal Deck Floor and Roof Assemblies:*

13.1.1 *Purpose*—These tests are intended to evaluate the tension and shear performance of anchors installed through metal decking into concrete fill.

13.1.2 *Test Members for Testing Anchors Installed in the Soffit of Concrete Fill on Metal Deck Floor and Roof Assemblies*—Cast test members having the minimum concrete fill thickness, maximum decking depth, minimum flute width and minimum metal thickness specified. The concrete fill shall contain no reinforcing. Lightweight concrete fill shall be permitted to be used. Test members may be inverted and placed flat on the floor of the test facility to facilitate shear testing of anchors installed through the decking and into the fill concrete. Test set-up details are shown in Fig. 20.

13.1.3 *Anchor Installation*—Install anchors through the metal decking and into the concrete fill in accordance with manufacturer's instructions. (See Fig. 20). To determine anchor performance in the lower flute of metal decking, test anchors shall be installed as depicted in Fig. 20, with the maximum desired offset from the lower flute centerline. To determine anchor performance in the upper flute of metal decking, the test anchors shall be installed in the upper flute.

13.1.4 *Tension Test*—Perform tension tests with continuous measurement of load and displacement.

13.1.5 *Shear Test*—Perform shear tests with continuous measurement of load and displacement. The direction of the shear load shall be toward the closest edge, unless otherwise specified.

14. Failure Criteria

14.1 *Load and Displacement at Failure*—Determine the maximum test load and the corresponding displacement for each assembly tested.

14.2 *Failure Modes*—Failure of the anchorage occurs by one or more of the following modes:

14.2.1 Concrete breakout,
14.2.2 Pullout and pull-through,
14.2.3 Anchor rupture,
14.2.4 Bond,
14.2.5 Shear,
14.2.6 Pryout, and
14.2.7 Side-face blowout.

15. Report

15.1 Report the applicable information listed in Practice E575, all information pertinent to the type of test performed (static, seismic, fatigue or shock, cracked or uncracked base material), and specifically include the following:

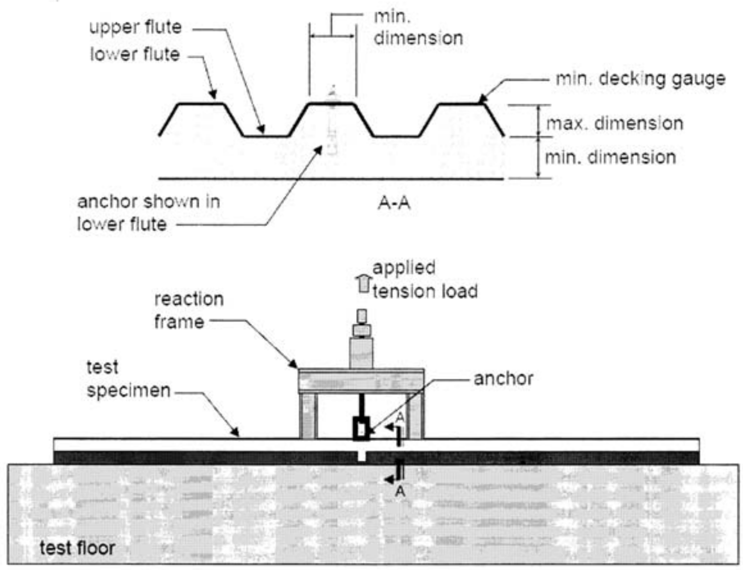


FIG. 20 Example of a Setup for Testing Anchors in Concrete Through Metal Decking

15.1.1 Dates of test and date of report;

15.1.2 Test sponsor and test agency;

15.1.3 Identification of anchors tested: manufacturer, model type, material, finish, shape, dimensions, and other pertinent information, such as cracks and other defects;

15.1.4 Description of the anchorage system tested and physical description of the structural member, including dimensions, installed reinforcing, etc.;

15.1.5 Detailed drawings or photographs of test specimens before and after testing if not fully described otherwise;

15.1.6 Physical characteristics of the test member into which the anchor(s) are embedded including mixture design of the concrete, aggregate type, compressive strength at time of test, and age of the test member at time of test;

15.1.7 Description of the procedure, tools, and materials used to install the anchorage system, and any deviation from those specified;

15.1.8 Age in hours or days of anchorage system, since installation, where applicable;

15.1.9 Temperature conditions at time of installation and at time of testing and any other temperature experience as required in Section 11;

15.1.10 Embedment depth of the installed anchors in in. [mm];

15.1.11 Torque, or number of turns (if this method is permitted), applied to the anchor prior to testing;

15.1.12 Description of test method, loading procedure used, actual rate of loading, and direction of shear loading;

15.1.13 Number of replicate specimens tested and results of all tested replicates;

15.1.14 Individual and average maximum load values, in lb-ft [kN] for each anchor tested, standard deviations and coefficients of variation, when applicable;

15.1.15 Individual and average displacement values at ultimate loads, in in. [mm] and standard deviations, or, when appropriate load-displacement curves, either as plotted directly or reprinted from data acquisition systems;

15.1.16 Description of the nature and type of failure exhibited by each anchor tested, including when appropriate, individual and average fatigue life values in cycles or the runout number of fatigue load cycles;

15.1.17 Photographs, sketches, or written descriptions of the failure modes observed;

15.1.18 Summary of findings; and

15.1.19 Listing of observers of tests and signatures of responsible persons.

16. Precision and Bias

16.1 Insufficient information is currently available to characterize the precision and bias of the test methods described here. As the test methods are more widely used, their precision and bias will be characterized.

17. Keywords

17.1 adhesive anchor; anchors; anchor capacity; cast-in-place anchor; concrete elements; creep test; environmental test; expansion anchor; fatigue; post-installed anchors; screw anchor; seismic; shear test; shock; static; sustained load test; tension test; test member; test methods