



Standard Test Method for Pullout Strength of Hardened Concrete¹

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1. Scope *

1.1 This test method covers determination of the pullout strength of hardened concrete by measuring the force required to pull an embedded metal insert and the attached concrete fragment from a concrete test specimen or structure. The insert is either cast into the fresh concrete or installed in hardened concrete.

1.2 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information purposes only.

1.3 The text of this test method references notes and footnotes which provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of this test method.

1.4 *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:

C 39/C 39M Test Method for Compressive Strength of Cylindrical Concrete Specimens²

C 670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials²

E 4 Practices for Force Verification of Testing Machines³

E 74 Practice of Calibration of Force Measuring Instruments for Verifying the Load Indication of Testing Machines³

3. Summary of Test Method

3.1 A metal insert is either cast into fresh concrete or installed into hardened concrete. When an estimate of the in-place strength is desired the insert is pulled by means of a jack reacting against a bearing ring. The pullout strength is determined by measuring the maximum force required to pull the insert from the concrete mass.

4. Significance and Use

4.1 For a given concrete and a given test apparatus, pullout strengths can be related to compressive strength test results. Such strength relationships depend on the configuration of the embedded insert, bearing ring dimensions, depth of embedment, and level of strength development in that concrete. Prior to use, these relationships must be established for each system and each new combination of concreting materials. Such relationships tend to be less variable where both pullout test specimens and compressive strength test specimens are of similar size, compacted to similar density, and cured under similar conditions.

NOTE 1—Published reports (1-16)⁴ by different researchers present their experiences in the use of pullout test equipment. Refer to ACI 228.1R (14) for guidance on establishing a strength relationship and interpreting test results. The Appendix provides a means for comparing pull-out strengths obtained using different configurations.

4.2 Pullout tests are used to determine whether the in-place strength of concrete has reached a specified level so that, for example:

- (1) post-tensioning may proceed;
- (2) forms and shores may be removed; or
- (3) winter protection and curing may be terminated.

In addition, post-installed pullout tests may be used to estimate the strength of concrete in existing constructions.

4.3 When planning pullout tests and analyzing test results, consideration should be given to the normally expected decrease of concrete strength with increasing height within a given concrete placement in a structural element. The measured pullout strength is indicative of the strength of concrete within the region represented by the conic frustum defined by the insert head and bearing ring. For typical surface installations, pullout strengths are indicative of the quality of the outer zone of concrete members and can be of benefit in evaluating the cover zone of reinforced concrete members.

4.4 Cast-in-place inserts require that their locations in the structure be planned in advance of concrete placement. Post-installed inserts can be placed at any desired location in the structure provided the requirements of 6.1 are satisfied.

4.5 This test method is not applicable to other types of post-installed tests that, if tested to failure, do not involve the same failure mechanism and do not produce the same conic

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² Annual Book of ASTM Standards, Vol 04.02.

³ Annual Book of ASTM Standards, Vol 03.01.

⁴ The boldface numbers refer to the list of references at the end of this test method.

*A Summary of Changes section appears at the end of this standard.

frustum as the cast-in-place test. (16).

5. Apparatus

5.1 The apparatus requires three basic sub-systems: a pull-out insert, a loading system, and a load-measuring system (Note 2). For post-installed inserts, additional equipment includes a core drill, a grinding wheel to prepare a flat bearing surface, a milling tool to undercut a groove to engage the insert, and an expansion tool to expand the insert into the groove.

NOTE 2—A center-pull hydraulic jack with a suitable pressure gage and bearing ring have been used satisfactorily.

5.1.1 Cast-in-place inserts shall be made of metal that does not react with cement. The insert shall consist of a cylindrical head and a shaft to fix embedment depth that is attached firmly to the center of the head (see Fig. 1). The insert shaft shall be threaded to the insert head so that it can be removed and replaced by a stronger shaft to pullout the insert, or it shall be an integral part of the insert and also function as the pullout shaft. Metal components of cast-in-place inserts and attachment hardware shall be of similar material to prevent galvanic corrosion. Post-installed inserts shall be designed so that they will fit into the drilled holes, and can be expanded subsequently to fit into the grooves that are undercut at a predetermined depth (see Fig. 2).

NOTE 3—A successful post-installed system uses a split ring that is coiled to fit into the core hole and then expanded into the groove.

5.1.2 The loading system shall consist of a bearing ring to be placed against the hardened concrete surface (see Figs. 1 and 2), and a loading apparatus with the necessary load-measuring devices that can be readily attached to the pullout shaft.

5.1.3 The test apparatus shall include centering features to ensure that the bearing ring is concentric with the insert, and that the applied load is axial to the pullout shaft, perpendicular to the bearing ring, and uniform on the bearing ring.

5.2 Equipment dimensions shall be determined as follows (see Figs. 1 and 2):

5.2.1 The diameter of the insert head (d_2) is the basis for defining the test geometry. The thickness of the insert head and

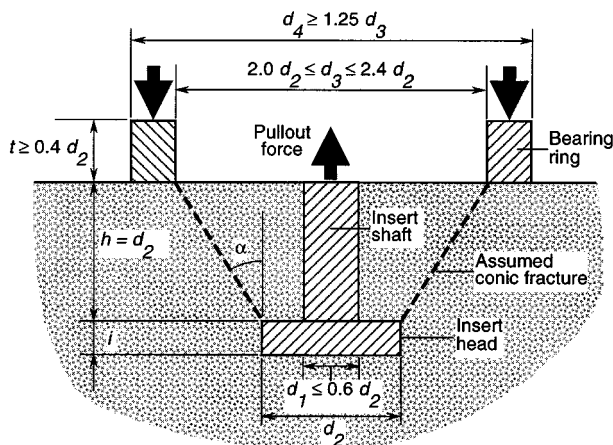


FIG. 1 Schematic Cross Section of Cast-in-Place Pullout Test

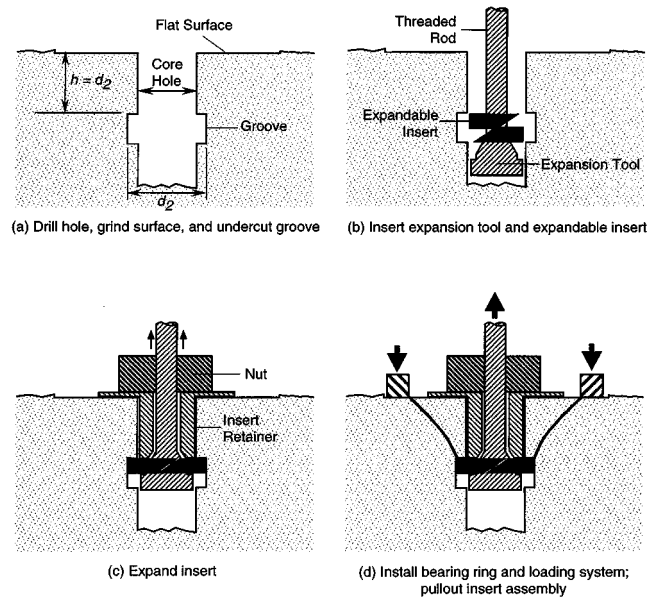


FIG. 2 Schematic of Procedure for Post-Installed Pullout Test

the yield strength of the metal shall be sufficient to avoid yielding of the insert during test. The sides of the insert head shall be smooth (see Note 5). The insert head diameter shall be greater than or equal to $\frac{2}{3}$ of the nominal maximum size of aggregate.

NOTE 4—Typical insert diameters are 25 and 30 mm (1 and 1.2 in.), but larger diameters have been used (1, 3). Tests (15) have shown that nominal maximum aggregate sizes up to 1.5 times the head diameter do not have significant effects on the strength relationships. Larger aggregate sizes may result in increased scatter of the test results because the particles can restrict normal pullout of the conic frustum.

NOTE 5—Cast-in-place inserts may be coated with a release agent to minimize bonding with the concrete, and they may be tapered to minimize side friction during testing. The insert head should be provided with the means, such as a notch, to prevent rotation in the concrete if the insert shaft has to be removed prior to performing the test. As a further precaution against rotation of the insert head, all threaded hardware should be checked prior to installation to ensure that it is free-turning and can be easily removed. A thread-lock compound is recommended to prevent loosening of the insert head from the shaft during installation and during vibration of the surrounding concrete.

5.2.2 For cast-in-place inserts, the length of the pullout insert shaft shall be such that the distance from the insert head to the concrete surface (h) equals the diameter of the insert head (d_2). The diameter of the insert shaft at the head (d_1) shall be no more than 0.60 times the head diameter.

5.2.3 For post-installed inserts, the groove to accept the expandable insert shall be cut so that the distance between the groove and concrete surface equals the insert diameter after expansion (d_2). The difference between the diameters of the undercut groove and the core hole (d_1) shall be sufficient to prevent localized failure and ensure that a conic frustum is extracted during the test (see Note 6). The expanded ring shall bear uniformly on the entire bearing area of the groove.

NOTE 6—A core hole diameter of 18 mm (0.71 in.) and an undercut groove diameter of 25 mm (1 in.) have been used successfully.

5.2.4 The bearing ring shall have an inside diameter (d_3) of 2.0 to 2.4 times the insert head diameter, and shall have an

outside diameter (d_4) of at least 1.25 times the inside diameter. The thickness of the ring (t) shall be at least 0.4 times the pullout insert head diameter.

5.2.5 Tolerances for dimensions of the pullout test inserts, bearing ring and embedment depth shall be $\pm 2\%$ within a given system.

NOTE 7—The limits for dimensions and configurations for pullout test inserts and apparatus are intended to accommodate various systems.

5.2.6 The loading apparatus shall have sufficient capacity to provide the loading rate prescribed in 7.4 and exceed the maximum load expected.

NOTE 8—Hydraulic pumps that provide a constant loading rate may give more uniform test results than pumps that apply the load intermittently.

5.2.7 The gage to measure the pullout force shall have a least division not larger than 5 % of the minimum value in the intended range of use.

NOTE 9—For the most accurate results, gages should have a maximum value indicator that preserves the value of the ultimate load when ultimate failure and subsequent stress release occur.

5.2.8 Pullout apparatus shall be calibrated in accordance with Annex A1 at least once a year and after all repairs. Calibrate the pullout apparatus using a testing machine verified in accordance with Practices E 4 or a Class A load cell as defined in Practice E 74. The indicated pullout force based on the calibration relationship shall be within $\pm 2\%$ of the force measured by the testing machine or load cell.

6. Sampling

6.1 Pullout test locations shall be separated so that the clear spacing between inserts is at least eight times the pullout insert head diameter. Clear spacing between the inserts and the edges of the concrete shall be at least four times the head diameter. Inserts shall be placed so that reinforcement is outside the expected conical failure surface by more than one bar diameter, or the maximum size of aggregate, whichever is greater.

NOTE 10—A reinforcement locator is recommended to assist in avoiding reinforcement when preparing post-installed tests. Follow the manufacturer's instructions for proper operation of such devices.

6.2 When pullout test results are used to assess the in-place strength in order to allow the start of critical construction operations, such as formwork removal or application of post tensioning, at least five individual pullout tests shall be performed as follows:

6.2.1 For a given placement, every 115 m³ (150 yd³), or a fraction thereof, or

6.2.2 For slabs or walls, every 470 m² (500 ft²), or a fraction thereof, of the surface area of one face.

Inserts shall be located in those portions of the structure that are critical in terms of exposure conditions and structural requirements.

6.3 When pullout tests are used for other purposes, the number of tests shall be determined by the specifier.

7. Procedure

7.1 Cast-in-Place Inserts:

7.1.1 Attach the pullout inserts to the forms using bolts or

by other acceptable methods that firmly secure the insert in its proper location prior to concrete placement. All inserts for the same tests shall be embedded to the same depth and each shaft shall be perpendicular to the formed surface.

NOTE 11—Inserts may be manually placed into unformed horizontal concrete surfaces. The inserts should be embedded into the fresh concrete by means that ensure a uniform embedment depth and a plane surface perpendicular to the axis of the insert shaft. Installation of inserts should be performed or supervised by experienced personnel. Experience indicates that pullout strengths are of lower value and more variable for manually-placed surface inserts than for inserts attached to the formwork.

7.1.2 When the concrete is to be tested, remove all hardware used for securing the pullout inserts in position. Before mounting the loading system, remove any debris or surface abnormalities to ensure a smooth bearing surface that is perpendicular to the axis of the insert.

7.2 Post-Installed Inserts:

7.2.1 The selected test surface shall be flat to provide a suitable working surface for drilling the core and undercutting the groove. Drill a core hole perpendicular to the surface to provide a reference point for subsequent operations and to accommodate the expandable insert and associated hardware. The use of an impact drill is not permitted.

7.2.2 If necessary, use a grinding wheel to prepare a flat surface so that the base of the milling tool is supported firmly during test preparation and so that the bearing ring is supported uniformly during testing. The ground surface shall be perpendicular to the axis of the core hole.

7.2.3 Use the milling tool to undercut a groove of the correct diameter at the correct depth in the core hole. The groove shall be concentric with the core hole.

NOTE 12—To control the accuracy of these operations, a support system should be used to hold the apparatus in the proper position during these steps.

7.2.4 If water is used as a coolant, remove free-standing water from the hole at the completion of the drilling and undercutting operations. Protect the hole from ingress of additional water until the completion of the test.

NOTE 13—Penetration of water into the failure zone could affect the measured pullout strength; therefore, water must be removed from the hole immediately after completion of drilling, grinding, and undercutting operations. If the test will not be completed immediately after preparation of the hole, water must not be allowed to enter the hole before completing the test.

7.2.5 Use the expansion tool to position the expandable insert into the groove and expand the insert to its proper size.

7.3 *Bearing Ring*—Place the bearing ring around the pullout insert shaft, connect the pullout shaft to the hydraulic ram, and tighten the pullout assembly snugly against the bearing surface, checking to see that the bearing ring is centered around the shaft and flush against the concrete.

7.4 *Loading Rate*—Apply load at a uniform rate so that the nominal normal stress on the assumed conical fracture surface increases at a rate of 70 ± 30 kPa/s (Note 14). If the insert is to be tested to rupture of the concrete, load at the specified uniform rate until rupture occurs. Record the maximum gage reading to the nearest half of the least division on the dial. If the insert is to be tested only to a specified level for acceptance,

load at the specified uniform rate until the specified pullout load is reached.

NOTE 14—The loading rate is specified in terms of a nominal stress rate to accommodate different sizes of pullout test systems. See Appendix X1 for the formula relating the nominal normal stress and the pullout load. For a pullout test system in which $d_2 = 25$ mm and $d_3 = 55$ mm, the specified stress rate corresponds to a loading rate of approximately 0.5 ± 0.2 kN/s. If this system is used, the ranges of the times to complete a test for different anticipated ultimate pullout loads would be as follows:

Anticipated Pullout Load, kN	Minimum Time, s	Maximum Time, s
10	14	33
20	29	67
30	43	100
40	57	133
50	71	167
60	86	200
70	100	233
80	114	267
90	129	300
100	143	333

7.5 **Rejection**—Reject a test result if one or more of the following conditions are encountered:

7.5.1 The large end of the conic frustum is not a complete circle of the same diameter as the inside diameter of the bearing ring;

7.5.2 The distance from the surface to the insert head (h in Fig. 1 or Fig. 2) is not equal to the insert diameter;

7.5.3 The diameter of the groove in a post-installed test is not equal to the design value;

7.5.4 The expanded insert diameter in a post-installed test is not equal to the design value; or,

7.5.5 A reinforcing bar is visible within the failure zone after the conic frustum is removed.

8. Calculation

8.1 Convert gage readings to pullout force on the basis of calibration data.

8.2 Compute the average and standard deviation of the pullout forces that represent tests of a given concrete placement.

9. Report

9.1 Report the following information:

9.1.1 Dimension of the pullout insert and bearing ring (sketch or define dimensions),

9.1.2 Identification by which the specific location of the pullout test can later be determined,

9.1.3 Date and time when the pullout test was performed.

9.1.4 For tests to failure, maximum pullout load of individual tests, average, and standard deviation, kN (lbf). For tests to a specified load, the pullout load applied in each test, kN (lbf).

9.1.5 Description of any surface abnormalities beneath the reaction ring at the test location,

9.1.6 Abnormalities in the ruptured specimen and in the loading cycle,

9.1.7 Concrete curing methods used and moisture condition of the concrete at time of test, and

9.1.8 Other information regarding unusual job conditions that may affect the pullout strength.

10. Precision and Bias

10.1 **Precision**—Based on the data summarized in ACI 228.1 R (14) for cast-in-place pullout tests with embedment of about 25 mm (1 in.), the average coefficient of variation for tests made on concrete with maximum aggregate of 19 mm ($\frac{3}{4}$ in.) by a single operator using the same test device is 8 %⁵. Therefore, the range in individual test results, expressed as a percentage of the average, should not exceed the following:

Number of Tests	Acceptable range, (percent of average)
5	31 %
7	34 %
10	36 %

Similar values of within-test variability have been reported for post-installed pullout tests of the same geometry as cast-in-place tests (15).

NOTE 15—If the range of tests results exceeds the acceptable range, further investigation should be carried out. Abnormal test results could be due to improper procedures or equipment malfunction. The user should investigate potential causes of outliers and disregard those test results for which reasons for the outlying results can be identified positively. If there are no obvious causes of the extreme values, it is probable that there are real differences in concrete strength at different test locations. These differences could be due to variations in mixture proportions, degree of consolidation, or curing conditions.

10.2 **Bias**—The bias of this test method cannot be evaluated since pullout strength can only be determined in terms of this test method.

11. Keywords

11.1 concrete strength; in-place strength; in-place testing; pullout test

⁵ This number represents the (1s%) limit as described in Practice C 670.

A1. CALIBRATION OF PULLOUT-HYDRAULIC LOADING SYSTEM

A1.1 The objective of the calibration procedure is to establish a relationship between the reading of the pullout force measuring system and the tensile force in the shaft used to pullout the insert. This relationship is established using alternative approaches as indicated in Fig. A1.1. In general, calibration is achieved by correlating the gage reading of the pullout loading system with the force measured by a testing machine that has been verified in accordance with Practices E 4 or a Class A load cell that has been calibrated in accordance with Practice E 74. The time interval between testing machine verifications or load cell calibrations shall be as defined in Practices E 4 or E 74.

A1.2 Position the pullout loading system on the force measurement apparatus. Align all components so that the

pullout force is concentric with the loading system and the force measurement system. Use spherical seats or other similar means to minimize bending effects in the loading system.

NOTE A1.1—When a compression-testing machine is used to measure the force, the bearing blocks should be protected against damage. Cold-rolled steel plate at least 13 mm (½ in.) thick is recommended.

A1.3 Using the pullout loading system, apply increasing loads over the operating range, and record the gage reading and the corresponding force measured by the testing machine or load cell. Take readings at approximately 10 load levels distributed over the operating range of the pullout loading system.

NOTE A1.2—Low values of force should be avoided in the calibration

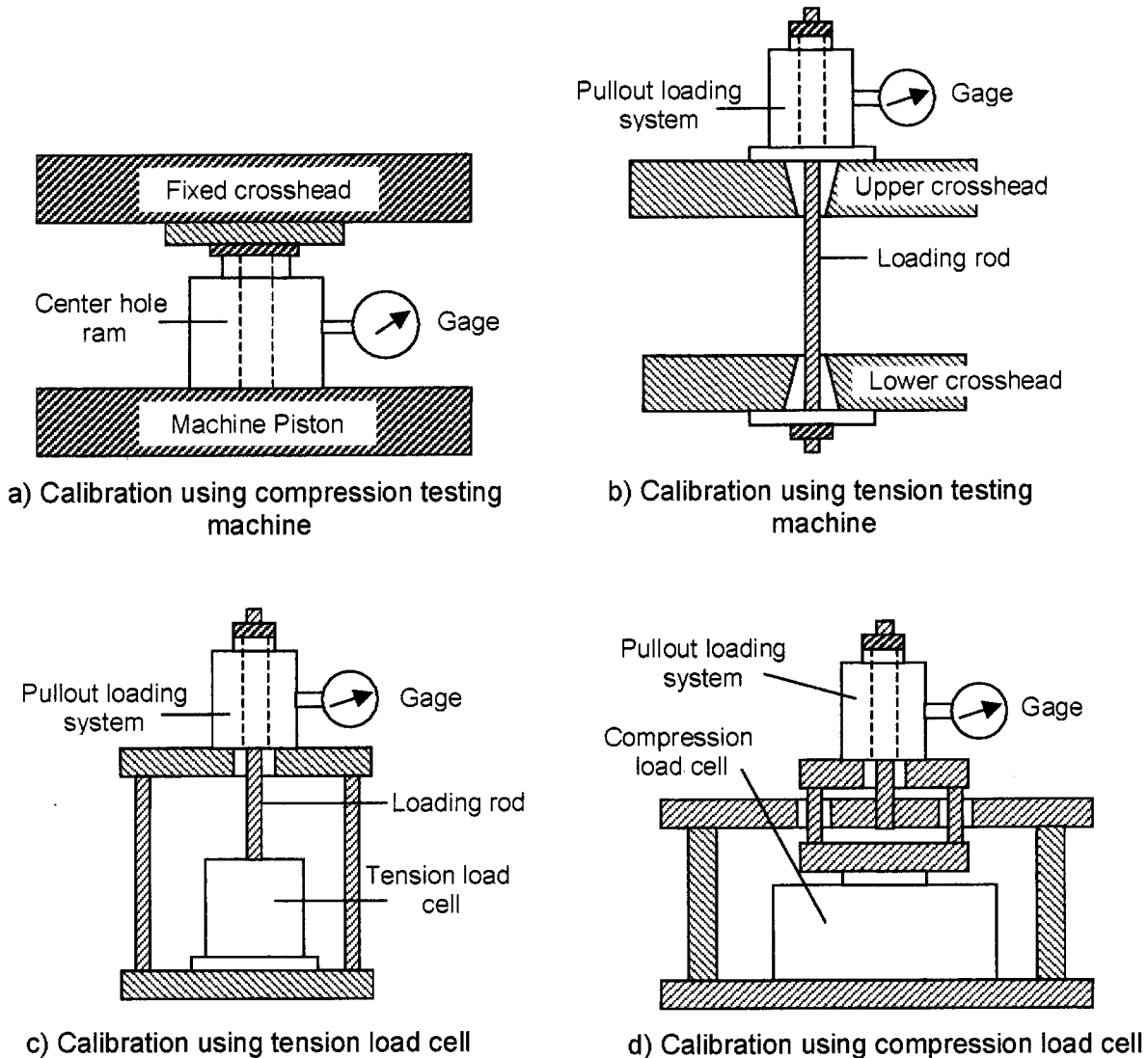


FIG. A1.1 Schematics of Acceptable Methods to Calibrate Pullout Load Measuring System

process because the effects of friction may introduce significant errors. The manufacturer should provide the operating range of the pullout loading system.

A1.4 Using readings obtained during calibration loading, calculate an appropriate regression equation using the least-squares curve-fitting method.

NOTE A1.3—Appendix X2 provides an example to illustrate the development of a calibration equation. Additional information is provided in Practice E 74.

A1.5 The difference between the force based on the regression equation and the force measured by the testing machine or the load cell shall not be greater than $\pm 2\%$ of the measured force over the operating range. If this tolerance is not met, the pullout loading system shall not be used until this requirement is satisfied.

APPENDIXES

(Nonmandatory Information)

X1. STRESS CALCULATION

X1.1 When a stress calculation is desired, compute a nominal normal stress on the assumed conical fracture surface by dividing the pullout force by the area of the frustum and multiplying by the sine of one-half the apex angle (see Figs. 1 and 2). Use the following equations:

$$f_n = (P/A) \sin \alpha \quad (X1.1)$$

$$\sin \alpha = (d_3 - d_2)/2S \quad (X1.2)$$

$$A = \pi S (d_3 + d_2)/2 \quad (X1.3)$$

$$S = \sqrt{h^2 + ((d_3 - d_2)/2)^2} \quad (X1.4)$$

where:

f_n = nominal normal stress, MPa (psi),
 P = pullout force, N (lbf),

α = $\frac{1}{2}$ the frustum apex angle, or $\tan^{-1} (d_3 - d_2)/2h$,
 A = fracture surface area, mm^2 (in.^2),
 d_2 = diameter of pullout insert head, mm (in.),
 d_3 = inside diameter of bearing ring or large base diameter of assumed conic frustum, mm (in.),
 h = height of conic frustum, from insert head to large-base surface, mm (in.), and
 S = slant height of the frustum, mm (in.).

X1.2 The above calculation gives the value of the average normal stress on the assumed failure surface shown in Fig. 1. Because the state of stress on the conic frustum is not uniform, the calculated normal stress is a fictitious value. The calculated normal stress is useful when comparing pullout strengths obtained with different test geometries that fall within the limits of this test method.

X2. EXAMPLE TO ILLUSTRATE CALIBRATION PROCESS

X2.1 This appendix provides an example to illustrate the development of the calibration equation to convert the gage reading on the pullout loading system to the force acting on the insert. Table X2.1 shows data that were obtained using the procedure in the annex. The first column shows the gage

reading and the second column is the measured force.

TABLE X2.1 Example of Calibration Data and Residuals After Regression

Gage Reading, kN	Measured Force, kN	Residuals, kN
2.0	1.6	0.03
5.0	4.8	0.09
10.0	10.5	-0.16
15.0	15.8	-0.02
20.0	21.2	0.03
25.0	26.7	-0.03
30.0	32.0	0.12
35.0	37.4	0.16
40.0	42.8	0.21
45.0	48.6	-0.14
50.0	54.2	-0.30
55.0	59.4	-0.06
60.0	64.5	0.29

X2.2 Fig. X2.1 shows a plot of the data in Table X2.1 along with the best-fit straight line to the data. A straight line was fitted using a commercial computer program for graphing and statistical analysis. The equation of the line is shown in the table of results on the graph and is as follows:

$$P \text{ (kN)} = -0.55 + 1.089 G \text{ (kN)} \quad (X2.1)$$

where:

P = estimated pullout force, kN, and
 G = pullout force indicated by gage of pullout loading system, kN.

The column labeled "error" in the table shown within Fig. X2.1 represents the standard deviation of the estimated intercept and slope. The low values of these standard deviations indicate that the intercept is not zero and that the slope is not equal to 1.00.

X2.3 Fig. X2.2 is a plot of the residuals of the best-fit line

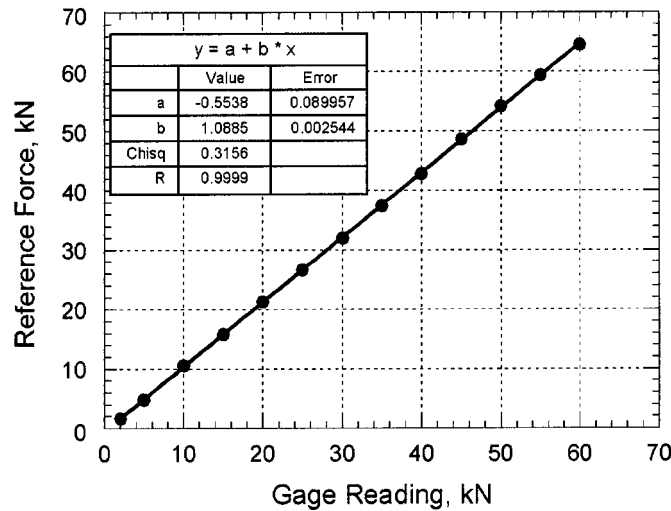


FIG. X2.1 Plot of Calibration Data from Table X2.1 and Best-Fit Straight Line

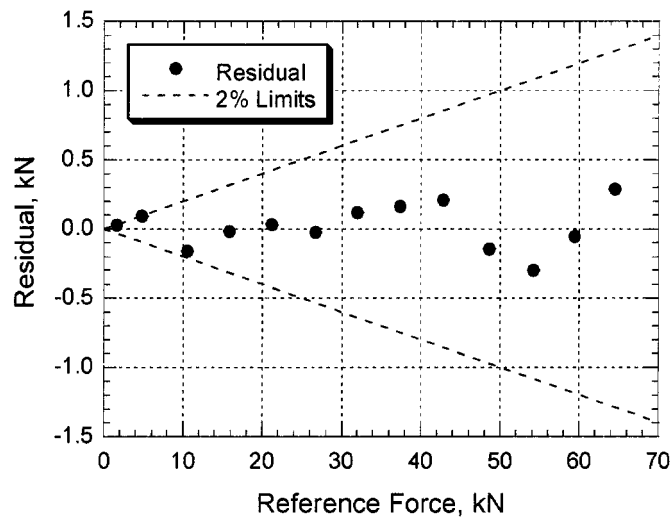


FIG. X2.2 Residuals of Best-Fit Equation as a Function of Measured Force

as a function of the measured force. These residuals are shown in the third column of Table X2.1 and are the differences between the estimated force based on the best-fit equation and the measured force (Column 2 in Table X2.1). Also shown in Fig. X2.2 are the $\pm 2\%$ limits required in accordance with 5.2.8. It is seen that with the exception of the first three points, the residuals are well within the permitted tolerance. Thus, the calibration relationship for this particular apparatus satisfies the requirements of 5.2.8 provided that the pullout force is greater than about 10 kN.

X2.4 Fig. X2.2 shows that the residuals are not randomly distributed but appear to have a periodic variation with the level of force. This indicates that the true calibration equation is not a straight line. However, because the residuals are well below the $\pm 2\%$ limits, it is not necessary to try to fit a higher order (polynomial) equation, and the straight line is adequate. Additional discussion on fitting higher order equations is provided in Practice E 74.

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SUMMARY OF CHANGES

The following changes to this test method have been incorporated since the last issue:

- (1) 5.2.8 was revised to indicate the minimum accuracy of the measured pullout force.
- (2) 7.4 was revised and specifies the loading rate in terms of the nominal tensile stress. Note 14 was added to provide guidance on implementing the new requirement.
- (3) The Annex was revised and includes more guidance on acceptable calibration methods.
- (4) A new Appendix X2 was added to illustrate the treatment of calibration data.

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