



## Standard Test Methods for In Situ Measurement Of Masonry Mortar Joint Shear Strength Index<sup>1</sup>

This standard is issued under the fixed designation C 1531; 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 ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

### 1. Scope\*

1.1 These test methods cover procedures for the determination of the average in situ mortar joint shear strength index in existing unreinforced solid-unit and ungrouted hollow-unit masonry built with clay or concrete units. Three methods are provided:

1.1.1 *Method A (with Flatjacks Controlling Normal Compressive Stress)*—For determining mortar joint shear strength index when the state of normal compressive stress at the test site is controlled during the test using the flatjack method described in Test Method C 1197. Horizontal displacement of the test unit is monitored throughout the test. The test setup for Method A is shown in Fig. 1.

1.1.2 *Method B (without Flatjacks Controlling Normal Compressive Stress)*—For determining mortar joint shear strength index when using an estimate of the normal compressive stress at the location of the test site. Horizontal displacement of the test unit is not monitored during this procedure. The test set up for Method B is shown in Fig. 2.

1.1.3 *Method C (with Flatjack Applying Horizontal Load)*—For determining mortar joint shear strength index using an estimate of the normal compressive stress at the location of the test site, as shown in Fig. 3. Horizontal displacement of the test unit is generally not measured during this procedure.

1.2 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information only.

1.3 *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 43 Terminology of Structural Clay Products<sup>2</sup>

C 1180 Terminology of Mortar and Grout for Unit Masonry<sup>2</sup>

C 1196 Test Method for In Situ Compressive Stress Within Solid Unit Masonry Estimated Using Flatjack Measurements<sup>2</sup>

C 1197 Test Method for In Situ Measurement of Masonry Deformability Properties Using the Flatjack Method<sup>2</sup>

C 1209 Terminology of Concrete Masonry Units and Related Units<sup>2</sup>

C 1232 Terminology of Masonry<sup>2</sup>

E 4 Practices for Force Verification of Testing Machines<sup>3</sup>

#### 2.2 Other Document:

Uniform Code for Building Conservation (Appendix Chapter 1, Earthquake Hazard Reduction in Existing Unreinforced Masonry Buildings), International Conference of Building Officials, Whittier, CA, 1997

### 3. Terminology

3.1 Terminology defined in Terminologies C 43, C 1180, C 1209, and C 1232 shall apply for these test methods.

### 4. Summary of Test Method

4.1 The in-place shear test is used to provide an index of the in situ, horizontal shear resistance of mortar joints in unreinforced masonry. For Method A, a single masonry unit is removed from opposite ends of the chosen test unit as shown in Fig. 1. For Method B, a single masonry unit and a head joint are removed from opposite ends of the chosen test unit, as shown in Fig. 2. For Method C, head joints on both ends of the tested unit are removed as shown in Fig. 3. Ensure that the bed joints are not disturbed in the unit to be tested. The test unit is then displaced horizontally relative to the surrounding masonry using a hydraulic jack or specialized flatjacks. The horizontal force required to cause first movement of the test unit provides a measured index of the mortar joint shear strength.

### 5. Significance and Use

5.1 The masonry mortar joint shear strength index obtained by this test method is related to the masonry wall shear strength by a relationship contained within Appendix Chapter 1 of the Uniform Code for Building Conservation. The user of this

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<sup>2</sup> *Annual Book of ASTM Standards*, Vol 04.05

<sup>3</sup> *Annual Book of ASTM Standards*, Vol 03.01.

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

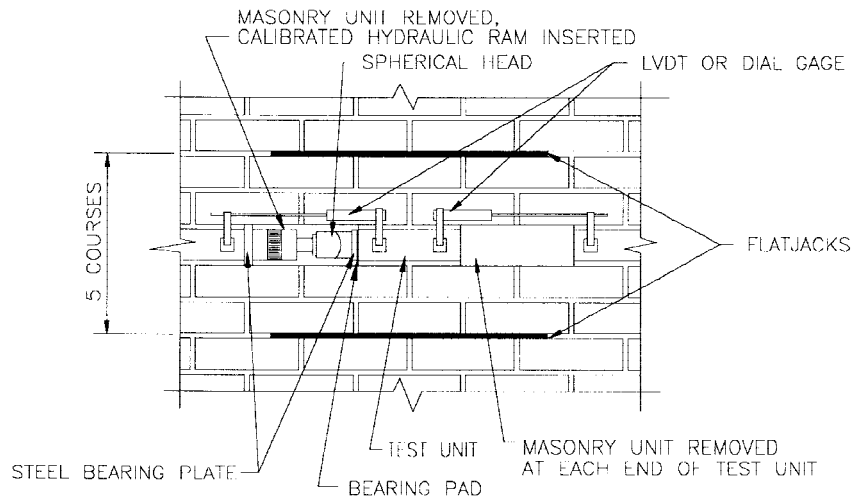


FIG. 1 Test Setup—Method A

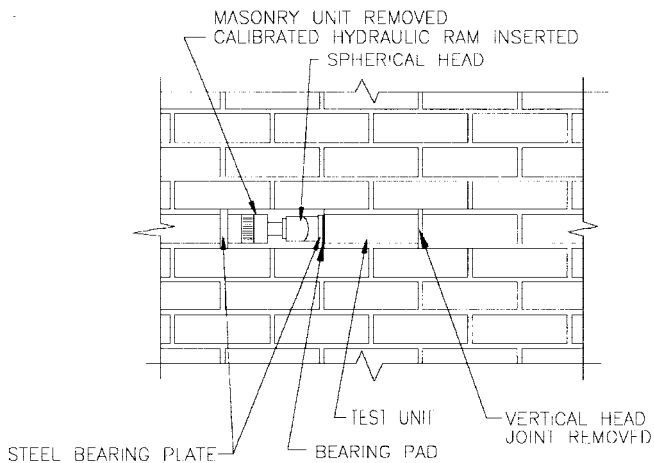


FIG. 2 Test Setup—Method B

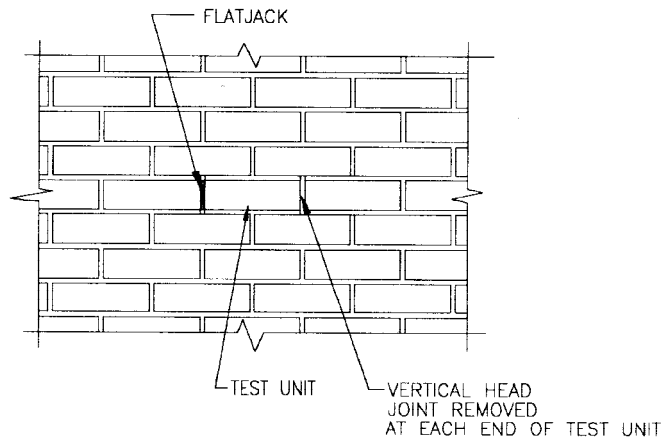


FIG. 3 Test Setup—Method C

standard is cautioned that the shear strength relationship contained within the Uniform Code for Building Conservation is an empirical relationship based on tests of early 20th-century unreinforced brick masonry. The relationship assumes that wall shear strength is limited by shear of the mortar joints rather than shear through the units.

5.2 For hollow ungrouted or solid unit masonry construction the shear strength index is measured only for the mortar bed joints vertically adjacent to the unit being tested. When testing hollow ungrouted masonry construction, the shear strength index is based on the horizontal interface between the mortar and the test unit and the masonry above and below the test unit. In the case of multi-wythe construction, the measured mortar joint shear strength index is applicable only to the wythe in which the test unit is located; no headers shall exist immediately above or below the test unit. The contribution of any existing collar joint mortar to the measured shear strength index is neglected, and this may lead to an overestimate of the shear strength index.

5.3 The test procedure listed for Method A may be conducted as an extension of Test Method C 1197. The two-flatjack test, conducted in accordance with Test Method C 1197, provides half of the required test setup for Method A. At the completion of the Method A test, one would know the measured normal compressive stress, the deformability of the masonry at the test, and the relationship between the expected joint shear strength index and the normal compressive stress.

## 6. Apparatus

6.1 The following equipment is required for both Method A and Method B:

6.1.1 Equipment to measure load; two options exist: (1) A hydraulic jack with an appropriate working pressure range to load the test unit. The force output of the jack throughout its working pressure range shall be known, to facilitate conversion between hydraulic pressure and force applied to the masonry; (2) For more precision, use a load cell to measure the force applied by the hydraulic jack. Verify load in accordance with Practices E 4. Place the load cell between the spherical seat and the bearing plate nearest the test unit.

6.1.2 Steel bearing plates shall be provided at each end of the test jack to distribute the load uniformly across the ends of the test unit and the reaction unit as shown in Fig. 1. The bearing plates shall have a minimum thickness equal to  $\frac{1}{8}$  the vertical dimension of the bearing plate. The bearing plates shall have a vertical dimension that is  $\frac{1}{8}$  in. (3.2 mm) less than the height of the unit; the plate shall be centered vertically on the end of the unit. The bearing plate shall have a horizontal dimension that equals or exceeds the thickness of the unit. The bearing plate surface in contact with the loaded unit shall be faced with a neoprene pad  $\frac{1}{16}$  in. (1.6 mm) thick; the pad shall have a durometer hardness in the range of 50 to 60.

6.1.3 An electrically or manually operated hydraulic pump with hydraulic hoses to pressurize the loading jack. Measure pressure using gauges calibrated to a traceable standard having both an accuracy of 1 % of full hydraulic scale and an appropriate operating range. The pressure gage shall have a peak hold feature to indicate the maximum hydraulic pressure attained during specimen loading. The hydraulic system shall be capable of maintaining constant pressure within 1 % of full scale for at least 5 min.

6.2 The following additional apparatus is required for Method A:

6.2.1 Flatjacks and associated equipment to measure the state of compressive stress as described in Test Method C 1196. Test Method C 1197 describes apparatus necessary to apply a known state of normal compressive stress to the masonry at the test site using flatjacks.

6.2.2 Use mechanical extensometers or electronic devices to measure horizontal displacement of the unit. The method or device used to measure deformation shall be capable of deformation measurements up to  $\frac{1}{4}$  in. (6 mm). Deformation measurements shall have an accuracy of at least 0.005 % of gage length. Fasten brackets or other attachment devices securely to the surface of the masonry using a rigid adhesive.

6.3 The following equipment is required for Method C:

6.3.1 A small rectangular flatjack that is sized to fit in the head joint on one side of the test unit. The flatjack dimensions must not exceed the dimensions of the end of the tested unit to prevent load application to the mortar joints.

6.3.2 If load-deformation data are required, use instrumentation as described in 6.2.2.

## 7. State of Normal Compressive Stress

7.1 The magnitude of normal compressive stress will have a direct effect on the measured joint shear strength index and must be determined beforehand.

7.2 *Method A (with Flatjacks Controlling Normal Compressive Stress)*—Apply normal compressive stress using flatjacks. Place an upper flatjack two courses above and centered over the test unit to within a tolerance of  $\pm\frac{1}{8}$  in. (3 mm). Place a lower flatjack five courses below the upper flatjack, centered under the test unit to within a tolerance of  $\pm\frac{1}{8}$  in. (3 mm). A single masonry unit, located on the centerline midway between the two flatjacks, is the unit to be tested for measurement of joint shear strength. The slots and flatjack installation shall be in accordance with Test Method C 1197.

7.3 *Method B (without Flatjacks Controlling Normal Compressive Stress)*—Estimate and record the average normal

compressive stress on the unit based upon the location of the test unit in the structure and the estimated dead and acting live loads.

7.4 *Method C (with Flatjack Applying Horizontal Load)*—Estimate the average normal compressive stress using the method described in 7.3.

## 8. Preparation of Test Site

8.1 The location at which the joint shear strength index is measured is dictated by engineering objectives. Avoid areas in which the mortar joints appear to be nonparallel. The unit to be tested must be in the stretcher orientation. Locate the test site far enough from wall openings or ends so that the loading jack bears against enough masonry to resist forces generated during loading of the test unit. The basic arrangement is illustrated in Fig. 1 for Method A, in Fig. 2 for Method B, and in Fig. 3 for Method C. At the desired location the following steps must be taken to prepare the site for testing:

8.1.1 For Method A or Method B, provide a space for the loading jack by removing a unit on one end of the test unit. Do not remove a unit for Method C.

8.1.2 For Method A, if the joint shear strength index in opposite directions is to be determined, remove the unit at both ends of the test unit to isolate the joints being investigated. Otherwise, follow the procedure of 8.1.3. The mortar in the joints above and below the test specimen shall not extend beyond the vertical ends of the unit being tested.

8.1.3 For Method B, remove a masonry unit on one side of the test unit and the head joint on the opposite end of the test unit. The mortar in the joints above and below the test specimen shall not extend beyond the vertical ends of the unit being tested.

8.1.4 For Method C, remove the head joints on both ends of the test unit. The mortar in the joints above and below the test unit shall not extend beyond the vertical ends of the unit being tested.

8.2 For solid unit and solid grouted masonry construction, measure the width and length at the top and bottom of the test unit to an accuracy of  $\frac{1}{32}$  in. (0.8 mm). For hollow ungrouted masonry construction, measure the length at mid-height of each face to an accuracy of  $\frac{1}{32}$  in. (0.8 mm) and measure the minimum thickness of each face shell at a point  $\frac{1}{2}$  in. (12.7 mm) above the mortar-bed plane to an accuracy of  $\frac{1}{32}$  in. (0.8 mm).

## 9. Procedure

9.1 *Method A (with Flatjacks Controlling Normal Compressive Stress)*:

9.1.1 Instrument the test unit by attaching a dial gage or electronic displacement transducer as shown in Fig. 1. Place the loading jack, spherical seat, and bearing plates with bearing pads into the space next to the test unit. Shim the jack to provide a centered horizontal force on the test unit.

9.1.2 Set the pressure in the two flatjacks equal to 10 psi (0.07 MPa) or less and close the valve. Increase pressure in the horizontal loading jack gradually, such that failure of the joint occurs between 30 s and 2 min after initial loading, recording displacement of the unit at small increments of horizontal load. Monitor the flatjack pressure during loading and adjust the

internal pressure, if necessary, to provide a constant normal compressive stress. When the bond between the unit and mortar joints is broken, the unit will begin to displace continuously under constant horizontal load. This represents the maximum horizontal load for this level of normal compressive stress.

9.1.3 Increase the pressure in the flatjacks to induce the next desired level of normal compressive stress and repeat the process of horizontal loading until the maximum horizontal load for this level of normal compressive stress is reached. Repeat the sequence in this manner to determine the bed joint shear stress at various levels of normal compressive stress.

9.1.4 To investigate the effect of shear force reversal on the in situ shear strength, if desired, the horizontal jack may be transferred to the opening on the opposite side of the test unit, the displacement instrumentation reversed, and the test sequence repeated in the opposite direction.

9.1.5 Release pressure in the horizontal jack after the final displacement measurement has been taken and remove the loading jack. Release pressure in the flatjacks and remove the flatjacks and displacement measurement devices. Any voids or slots created during site preparation are permitted to be filled using the original or similar units and a mortar or other suitable material of a color and strength similar to the original mortar.

9.2 *Method B (without Flatjacks Controlling Normal Compressive Stress):*

9.2.1 Place the loading jack, spherical seat (if used), and bearing plates into the space next to the test unit. Shim the jack to provide a centered horizontal force on the test unit. Increase pressure in the hydraulic jack gradually until the test unit begins to displace continually under a constant level of horizontal load. Record the maximum load indicated by the pressure gage or load cell.

9.2.2 Release the pressure from the loading jack and remove the jack. Any voids or slots created during site preparation are permitted to be filled using the original or similar units and a mortar or other suitable material of a color and strength similar to the original mortar.

9.3 *Method C (with Flatjack Applying Horizontal Load):*

9.3.1 Insert the small flatjack into the head joint at one end of the test unit. Apply a small amount of pressure sufficient to seat the flatjack in the head joint using the hydraulic pump. Check the alignment of the flatjack in the head joint. Ensure that the flatjack is centered on the test unit (top to bottom and front to back) and is square with the test unit.

9.3.2 Increase pressure on the flatjack gradually until a crack appears or slip occurs. Record the maximum pressure as indicated by the pressure gauge.

9.3.3 Release the pressure from the flatjack and remove the jack. Any voids or slots created during site preparation are permitted to be filled using the original or similar units and a mortar or other suitable material of a color and strength similar to the original mortar.

## 10. Calculation

10.1 *Method A (with Flatjack Controlling Normal Compressive Stress)*—Calculate the average mortar joint shear strength-index  $\tau_i$  for each level of normal compressive stress,  $\sigma_v$ , as:

$$\tau_i = \frac{P_{hi}}{A_j}$$

where:

$P_{hi}$  = maximum horizontal force resisted by the test unit at the  $i$ th level of normal compressive stress, and  
 $A_j$  = gross area of upper and lower bed joints in the case of solid-unit masonry or the net mortar bedded area for the case of hollow-unit masonry.

Prepare a plot of joint shear strength index versus normal compressive stress,  $\sigma_v$ . The coefficient of friction of the masonry,  $\mu$ , is calculated as the slope of the best-fit straight line through these points. The joint shear strength index at zero nominal compression stress or adhesion stress,  $\tau_o$ , is calculated as the intersection of the best fit line to the vertical axis. Estimates of joint shear strength index at other levels of vertical compressive stress are calculated using the relation

$$\tau = \tau_o + \mu(\sigma_v)$$

where:

$\tau_o$  = joint shear strength index at zero normal compressive stress, or adhesion stress.

NOTE 1—Determination of normal (vertical) compressive stress on the test unit, as applied by flatjacks, is discussed in Appendix X1.

10.2 *Method B (without Flatjack Controlling Normal Compressive Stress)*—Calculate the average bed joint shear strength index,  $\tau$ , as:

$$\tau = \frac{P_h}{A_j}$$

where:

$P_h$  = maximum horizontal force resisted by the test unit, and  
 $A_j$  = gross area of upper and lower bed joints in the case of solid-unit masonry or the net mortar bedded area for the case of hollow-unit masonry.

The shear strength index from the test,  $\tau$ , is reduced to the value that would have been obtained under zero axial load  $\tau_o$ , using the relation

$$\tau_o = \tau - \mu(\sigma_v)$$

where:

$\mu$  = coefficient of friction for the masonry, and  
 $\sigma_v$  = estimated normal compressive stress at the test unit.

NOTE 2—Method A determines the friction coefficient  $\mu$ ; whereas in Method B the value of  $\mu$  is not measured but taken from available data. Laboratory studies have shown that the coefficient of friction between masonry units and mortar,  $\mu$ , varies from 0.3 to 1.6, with a mean value of 1.0 and coefficient of variation of approximately 30 %.

10.3 *Method C (with Flatjack Applying Horizontal Load)*—Calculate the average bed joint shear strength index,  $\tau$ , using the methods described in 10.2 except that the horizontal force is calculated as follows:



$$P_h = K_m \cdot A_f \cdot p$$

where:

$K_m$  = dimensionless constant that reflects the geometrical and stiffness properties of the flatjack. Determined in accordance with Test Method C 1197,

$A_f$  = area of the flatjack, and

$p$  = flatjack pressure at crack initiation or slip.

## 11. Report

11.1 Report each in situ bed joint shear strength index along with the following information:

11.1.1 Description of the testing conditions, such as site, geographical location, environmental conditions, temperature, building identification, date of construction (if available), and name of the engineer/technician conducting the test. Include details of the type and quality of construction, including an estimate of the percentage of mortar or grout in the collar joint, if applicable.

11.1.2 Identity and description of the specific test location in the structure and on an elevation drawing.

11.1.3 Description and sources (if possible) of the masonry materials at the test location.

11.1.4 Method used to determine joint shear strength index, a diagram of the test unit, adjacent masonry, and location of the loading jack, including all pertinent dimensions.

11.1.5 Description and source of instrumentation, hydraulic system, and other pertinent information.

11.1.6 Magnitude of normal compressive stress,  $\sigma_v$ , and method used for determination, including calculations.

11.1.7 Magnitude of measured bed joint shear strength index,  $\tau$ ; shear strength index calculated for zero vertical stress,  $\tau_0$ ; and coefficient of friction,  $\mu$ , used for calculations.

11.1.8 Other observations.

11.2 Additional information is required if Method A has been used, including all pertinent information regarding flatjack usage as required by Test Methods C 1196 and C 1197, description of deformation measuring devices used including locations, data sheets containing deformation measurements, joint shear strength index for each level of vertical compressive stress, test data, and calculations for determination of coefficient of friction,  $\mu$ .

## 12. Precision and Bias

12.1 Insufficient data exists to correlate the joint shear strength index measured with the in situ test to the actual shear strength index of the masonry. In situ measurement of bed joint shear strength and coefficient of friction may be affected by workmanship, the quality of the collar joint, and inaccuracies in determining normal compressive stress, whether estimated or controlled during testing using flatjacks.

12.2 Laboratory studies have shown that the in situ bed joint shear strength index test will generally overestimate the actual shear strength index of a wall panel; however, insufficient data currently exist to provide a reliable bias statement.

## 13. Keywords

13.1 coefficient of friction; flatjack; in situ; masonry; mortar joint; nondestructive evaluation; shear strength

# APPENDIX

## (Nonmandatory Information)

### X1. MAGNITUDE OF NORMAL COMPRESSIVE STRESS APPLIED BY FLATJACKS

X1.1 The Method A procedure, described above, is intended to allow the magnitude of normal compressive stress on the test unit to be controlled during testing. Past practice has been to assume that the normal stress on the test unit is equivalent to the uniform stress imposed upon the masonry by the flatjacks, however, recent analyses have shown the actual stress distribution on the test unit to be significantly different.

#### X1.2 Calculation of Normal Stress on Test Unit:

X1.2.1 It is necessary to modify the normal stress applied to the test unit by a factor  $j$  in order to convert the flatjack stress to normal stress on the test unit, using the following calculation:

$$\sigma_n = j(\sigma_{ff})$$

where:

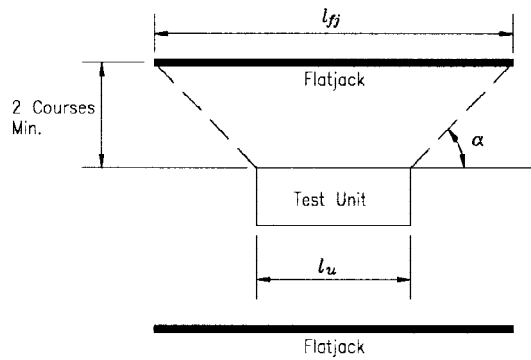
$\sigma_n$  = normal stress on the test unit,

$j$  = modification factor, and

$\sigma_{ff}$  = stress applied by the flatjacks to the masonry, computed in accordance with Test Method C 1197.

X1.3 Analytical models in the form of two- and three-dimensional finite element models have been developed for the shear test described in Method A to determine the normal stress distribution on the test joints. Analysis of an in situ shear test on a two-wythe brick masonry wall, set up as shown in Fig. X1.1, has shown that the distribution of normal stress on the test unit is nonuniform, with the average stress equivalent to 1.7 times the applied flatjack stress. Hence, the modification factor  $j$  is equal to 1.7 for this case.

X1.4 The value of  $j$  is unique for this particular configuration. It is reasonable to assume, however, that this factor may be applied in cases where the test configuration is proportional to that in Fig. 3. The angle  $\alpha$  shown in Fig. X1.1 may be used to compare different test configurations. For the analysis described above,  $\alpha$  equals approximately  $45^\circ$ . Hence, the modification factor  $j = 1.7$  may be used if the angle is equal to about  $45^\circ$ . Further analysis would have to be conducted to determine the actual state of normal stress acting on the test unit for other geometries and test configurations.



Analytical Model:

$$l_{fj} = 19.0 \text{ inches} \\ (48.3 \text{ cm})$$

$$l_u = 8.25 \text{ inches} \\ (21.0 \text{ cm})$$

$$\alpha = 45^\circ$$

FIG. X1.1 Geometrical Configuration of Analytical Model

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## SUMMARY OF CHANGES

Committee C15 has identified the location of selected changes to this standard since the last issue, C 1531–02, that may impact the use of this standard (Approved Jan. 10, 2003).

- (1) 6.1.2 was modified to specify that the steel bearing plates provided at the end of the test jack are to cover the entire thickness of the unit.
- (2) 8.2 was modified to specify that the length of hollow ungrouted masonry should be measured at mid-height of each face.
- (3) 9.1.2 and 9.1.3 were modified to clarify the language referring to stresses and displacement.
- (4) 9.1.5, 9.2.2, and 9.3.3 were modified to allow the use of original or similar units in repair of test areas.

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