Designation: E 2126 – 02a

An American National Standard

Standard Test Methods for Cyclic (Reversed) Load Test for Shear Resistance of ~~Framed~~ Walls for Buildings[1]

This standard is issued under the fixed designation E 2126; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 These test methods are designed to evaluate the shear stiffness, shear strength, and ductility of a wall assembly, including applicable shear connections and hold-down connectors, under quasi-static cyclic (reversed) load conditions.

1.2 These test methods are intended for wall assemblies constructed from wood or metal framing with solid sheathing or other bracing methods or structural insulated panels.

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:*

[1] These test methods are under the jurisdiction of ASTM Committee E06 on Performance of Buildings and are the direct responsibility of Subcommittee E06.11 on Horizontal and Vertical Structures/Structural Performance of Completed Structures.

Current edition approved ~~April~~ Oct. 10, 2002. Published ~~July~~ November 2002 ~~Last previous edition E 2126–01.~~ Originally published as E 2126–01. Last previous edition E 2126–02.

D 2395 Test Methods for Specific Gravity of Wood and Wood-Based Materials[2]
D 4442 Test Methods for Direct Moisture Content Measurement of Wood and Wood-Based Materials[2]
D 4444 Test Methods for Use and Calibration of Hand-Held Moisture Meters[2]
E 564 Practice for Static Load Test for Shear Resistance of Framed Walls for Buildings[3]
E 575 Practice for Reporting Data from Structural Tests of Building Constructions, Connections, and Assemblies[3]
E 631 Terminology of Building Constructions[3]
E 1803 Test Methods for Determining Structural Capacities of Insulated Panels[4]

3. Terminology

3.1 For definitions of terms used in this standard, see Terminology E 631.

3.2 *Definitions of Terms Specific to This Standard:*

3.~~1~~2.1 *ductility factor (μ), n*—the ratio of the ultimate displacement (Δ_u) and the yield displacement (Δ_{yield}).

3.~~1~~2.2 *envelope curve (see Fig. 1), n*—the locus of extremities of the load-displacement hysteresis loops. Initial envelope curve contains the peak loads from the first cycle of each phase of the cyclic loading. Wall displacement in the positive direction produces a positive envelope curve; the negative wall displacement produces a negative envelope curve. The positive direction is based on outward movement of the hydraulic actuator. The negative direction is based on inward movement of the actuator.

3.~~1~~2.3 *equivalent energy elastic-plastic (EEEP) curve (see Fig. 2), n*—an ideal elastic-plastic curve circumscribing an area equal to the area enclosed by the observed load-displacement curve or envelope curve between the origin, the ultimate displacement, and the displacement axis. The elastic portion of the EEEP curve contains the origin and has a slope equal to the elastic stiffness, k_e. The plastic portion is a horizontal line equal to P_{yield} determined by the following equation:

$$P_{yield} = \left(\Delta_u - \sqrt{\Delta_u^2 - \frac{2A}{k_e}}\right) k_e \qquad (1)$$

where:

P_{yield} = yield load (lbf or N);
A = the area (lbf·in. or N·m) under the observed load-displacement curve or envelope curve from zero to ultimate displacement (Δ_u);
k_e = elastic shear stiffness (lbf/in. or N/m) defined by the slope of the secant passing through the origin and a point on the observed load-displacement curve or envelope curve where the load equals 0.4 P_{peak}.

3.~~1~~2.4 *failure limit state, n*—the point in the load-displacement relationship corresponding to the last data point with the absolute load equal or greater than 0.8 P_{peak}.

3.~~1~~2.5 *failure load, n*—0.8 P_{peak}.

3.~~1~~2.6 *first major event (FME), n*—the first significant limit state to occur (see *limit state*).

3.~~1~~2.7 *limit state, n*—an event that marks the demarcation between two behavior states, at which time some structural behavior of the element or system is altered significantly.

3.~~1~~2.8 *strength limit state, n*—the point in the force-displacement relationship corresponding to the maximum absolute displacement at Δ_{peak} for the maximum absolute load (P_{peak}) resisted by the assembly.

---

[2] *Annual Book of ASTM Standards*, Vol 04.10.
[3] *Annual Book of ASTM Standards*, Vol 04.11.
[4] *Annual Book of ASTM Standards*, Vol 04.12.

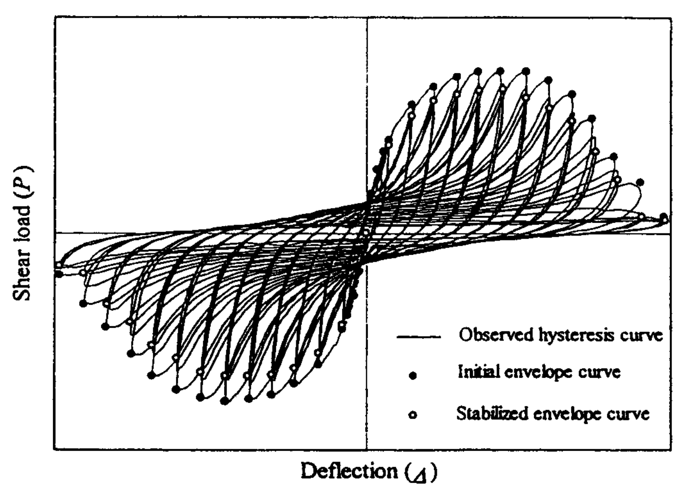

FIG. 1 Observed Hysteresis Curve and Envelope Curves

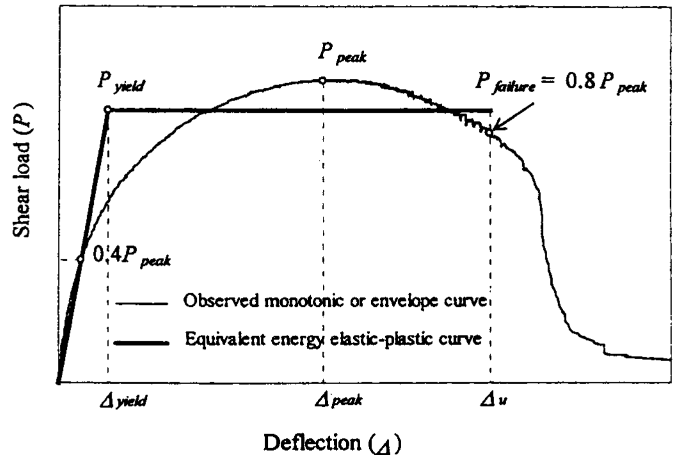

FIG. 2 Performance Parameters of Shear-Wall Assembly

3.~~1~~2.9 *ultimate displacement* (Δ_u) , *n*—the displacement corresponding to the failure limit state.

3.~~1~~2.10 *yield limit state*, *n*—the point in the load-displacement relationship where the elastic shear stiffness of the assembly decreases 5 % or more. For assemblies with nonlinear ductile elastic response, the yield point (Δ_{yield}, P_{yield}) is permitted to be determined using the equivalent energy elastic-plastic curve (see 3.~~1~~2.3).

4. Summary of Test Method

4.1 The cyclic shear stiffness, shear strength and ductility of walls are determined by subjecting a wall assembly to full-reversal cyclic racking shear loads. This is accomplished by anchoring the bottom edge of the wall assembly to a rigid base and applying a force parallel to the top of the wall. The test assembly is allowed to displace in its own plane. As the wall assembly is racked to specified displacement increments, the racking (shear) force and displacements are continuously measured (see 8.6).

5. Significance and Use

5.1 These test methods are intended to measure the performance of~~ framed~~ walls subjected to earthquake loads. Since these loads are~~ dynamic and~~ cyclic, the loading process simulates the actions and their effects on the walls.

6. Wall Assembly

6.1 *General*—The typical wall assembly consists of a frame on which the elements comprising the wall, including the sheathing (or diagonal bracing members, if applicable) are placed. The elements shall be fastened to the frame in a manner to conform with 6.2. Elements used to construct wall assemblies may be varied to permit anticipated failure of selected~~ elements. Frameless wall assemblies are also permitted to be tested under the guidelines of these test methods.~~ elements.

6.2 *Connections*—The performance of framed walls is influenced by the type, spacing and edge distance of fasteners attaching sheathing to framing and spacing of the shear connections and hold-down connectors to the rigid base. All of these connections shall be consistent with the types used in actual building connections.

6.3 *Frame Requirements*— The frame of the wall assembly shall consist of materials representative of those to be used in the actual building construction. The connections of these members shall be consistent with those intended in actual building construction.

6.3.1 For wood framing members, record the species and grade of lumber used; moisture content of lumber at the time of fabrication and testing, if more than 24 h passes between these operations (see Test Methods D 4442, Method A or B; or D 4444, Method A or B); and specific gravity of the lumber (see Test Methods D 2395, Method A).

6.3.2 For steel or other metal framing members, record the material specifications and thickness.

6.4 *Structural Insulated Panel*—The panel is a prefabricated assembly consisting of an insulating core of 1.5 inches (38 mm) minimum sandwiched between two facings. The assembly is constructed by attaching panels together and to top and bottom plates or tracks.

6.5 *Wall Size*—The wall assembly shall have a height and length or aspect (height/length) ratio that is consistent with intended use requirements in actual building construction (see Fig. 3).

7. Test Setup

7.1 The wall assembly shall be tested such that all elements and sheathing surfaces are observable. For assemblies such as framed walls with sheathing on both faces of framing or frameless structural insulated panels, the assemblies are dismantled after tests to permit observation of all elements. The bottom of the~~ frame~~ wall shall be attached to a rigid base with shear connections as specified in 6.2. The test apparatus shall support the wall assembly as necessary to prevent displacement from the plane of the wall, but in-plane displacement shall not be restricted.

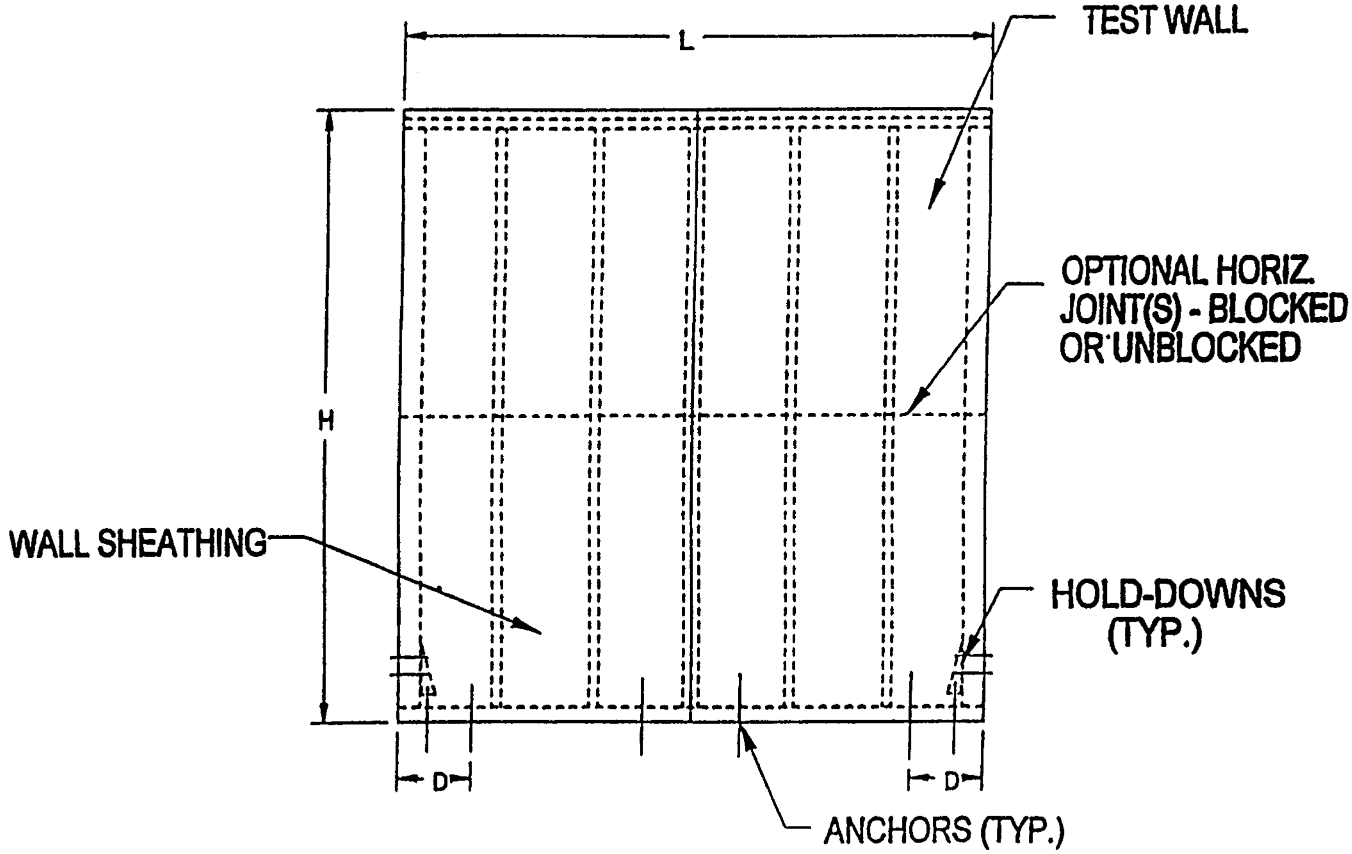

FIG. 3 Cyclic Load Shear Wall Test Specimen

8. Procedure

8.1 *Number of Tests*— A minimum of two identical wall assemblies shall be tested to determine the maximum shear stiffness and maximum shear strength of a given construction. These values shall be calculated in accordance with Section 9. If these force-displacement relationships do not agree within 10 % of the lower value, test a third identical wall assembly, and compute the mean value based on the number of walls tested.

8.2 Apply racking shear load horizontally in the plane of the wall to the top of the wall assembly (along the ~~axis of the frame~~ axis) (Fig. 4~~). A~~) using a programmable double-acting hydraulic actuator with ~~an integral~~ load ~~cell is suggested for conducting the tests.~~ cell. The cyclic displacement of the actuator shall be controlled to follow a cyclic displacement procedure described in either 8.3 (Method A) or 8.4 (Method B).

8.2.1 The first major event (FME) and the ultimate displacement (Δ_u) shall be determined from a preliminary monotonic load test on an identical wall assembly in accordance with Practice E 564.

8.3 *Method A (Sequential-Phased Displacement Procedure)*:

8.3.1 *Sequential Phased Displacement (SPD) Loading Procedure*—Displacement-controlled loading procedure that involves displacement cycles grouped in phases at incrementally increasing displacement levels. The cycles shall form either a sinusoidal wave or a triangular wave. The SPD loading consists of two displacement patterns and is illustrated in Fig. 5. The first displacement pattern consists of three phases, each containing three fully-reversing cycles of equal amplitude, at displacements representing 25 %, 50 % and 75 % of anticipated FME. The second displacement pattern is illustrated in Fig. 6. Each phase is associated with a respective displacement level and contains one initial cycle, three decay cycles and a number of stabilization cycles. Stabilized response is defined as a decrease in load between two successive cycles of not more than 5 %. For nailed wood-frame shear walls, three stabilization cycles are sufficient to obtain a stabilized response. The amplitude of each consecutive decay cycle decreases by 25 % of the initial displacement.

8.3.2 The schedule of amplitude increments between the sequential phases is given in Table 1. The amplitude increments selected for the SPD procedure are based on the FME and the ductility factor, μ, determined from the preliminary cyclic monotonic load test.

8.4 *Method B*:

8.4.1 The sequence of amplitudes (see Table ~~1)~~ 2) of the reversed cycles in Method B is a function of the ultimate displacement (Δ_u) obtained from the preliminary static test.

8.4.2 The test loading procedure is given in Fig. ~~4~~ 7 and Table ~~2.~~ 2. The schedule includes two displacement patterns of gradually increasing displacement amplitudes. During the first pattern, the amplitude is increased with each cycle until 0.2 Δ_u is

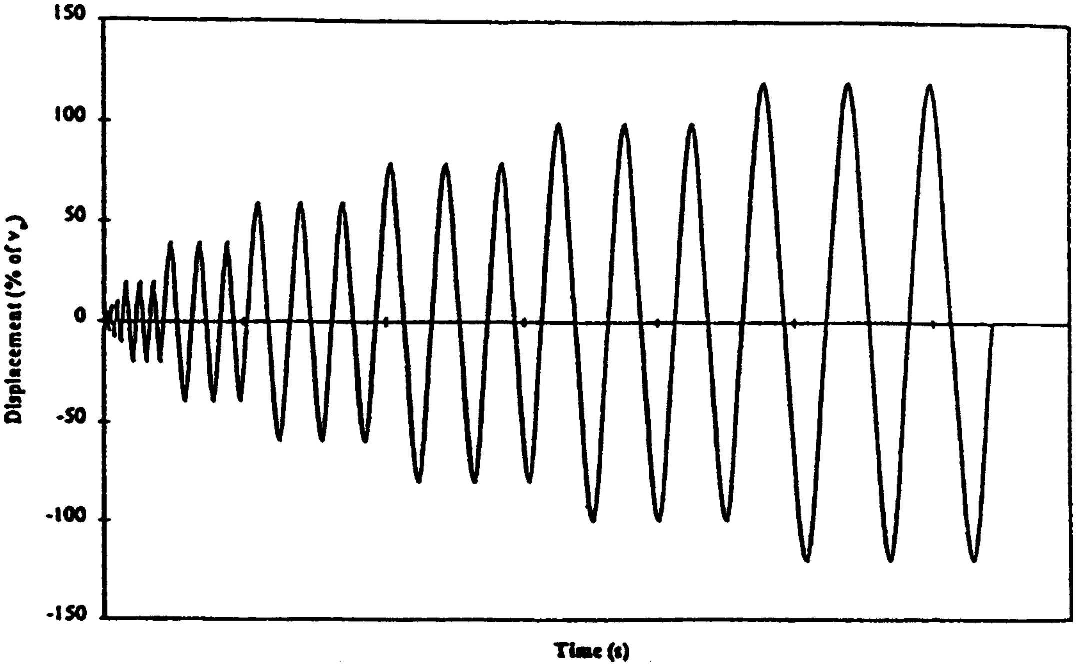

FIG. 4 7 Cycle Displacement Schedule

reached. During the second pattern, a minimum of three cycles are applied at each amplitude to achieve the stabilized response at each step (see 8.3.1).

8.5 The actuator displacement in either Method A or B shall be controlled at either constant cyclic frequency or at a constant rate of displacement. The rate of displacement shall be between 0.04 and 5.0 in. (1.0 and 127 mm)/s. The cyclic frequency shall range from 0.2 to 1.0 Hz (one cycle/s) to avoid inertial effects of the mass of the wall and test fixture hardware during cyclic loading. The loading shall follow the corresponding procedure until the applied load diminishes more than 0.2 P_{peak}, that is, until the failure limit state occurs.

8.6 Displacements shall be measured with displacement measuring devices with a resolution of 0.005 in. (0.13 mm) or other suitable devices for continuously measuring displacement under cyclic loading conditions, at a minimum sampling rate of 100 readings/cycle. The following instrumentation shall be provided for measuring displacements, and hold-down connector forces when required:

8.6.1 Horizontal displacement of the wall at the top plate.

8.6.2 Vertical displacement of both end posts (uplift and compression) relative to the rigid base. The reference point for this measurement shall be on or immediately adjacent to the outside face of the end post.

8.6.3 Horizontal displacement of the bottom plate relative to the rigid base (lateral in-plane sliding).

8.6.4 Vertical displacement of the hold-down connectors relative to the end posts (deformation/fastener slip).

8.6.5 When specified, loads on the bolts fastening the hold-down connectors to the rigid base.

9. Calculation

9.1 Based on the observed hysteresis response curves, the initial and the stabilized envelope (positive and negative) curves are generated for each tested specimen. Determine mean values resulting from tests of identical wall assemblies (see 8.1). Calculate the following information from these tests:

9.1.1 *Maximum Shear Strength (v_{peak})*—The average of maximum absolute values of load per unit wall length resisted by the wall assembly in the negative and positive directions of displacement:

$$V_{peak} = \frac{P_{avg:peak}}{L} \tag{2}$$

where:

V_{peak}	=	maximum shear strength, lbf/ft (or N/m);
$P_{avg:peak}$	=	average of maximum absolute values of load resisted by the wall assembly in the negative and positive directions of displacement, lbf (or N), and
L	=	length of shear wall assembly, ft (or m).

9.1.2 *Stabilized Shear Strength ($V_{peakstab}$)*—The average of maximum absolute values of load per unit wall length resisted by the wall assembly during the stabilized cycle in the negative and positive directions of displacement (lbf/ft or N/m).

9.1.3 Using the negative and the positive envelope curves compute the secant shear modulus, G', at 0.4 P_{peak} and at P_{peak} as follows:

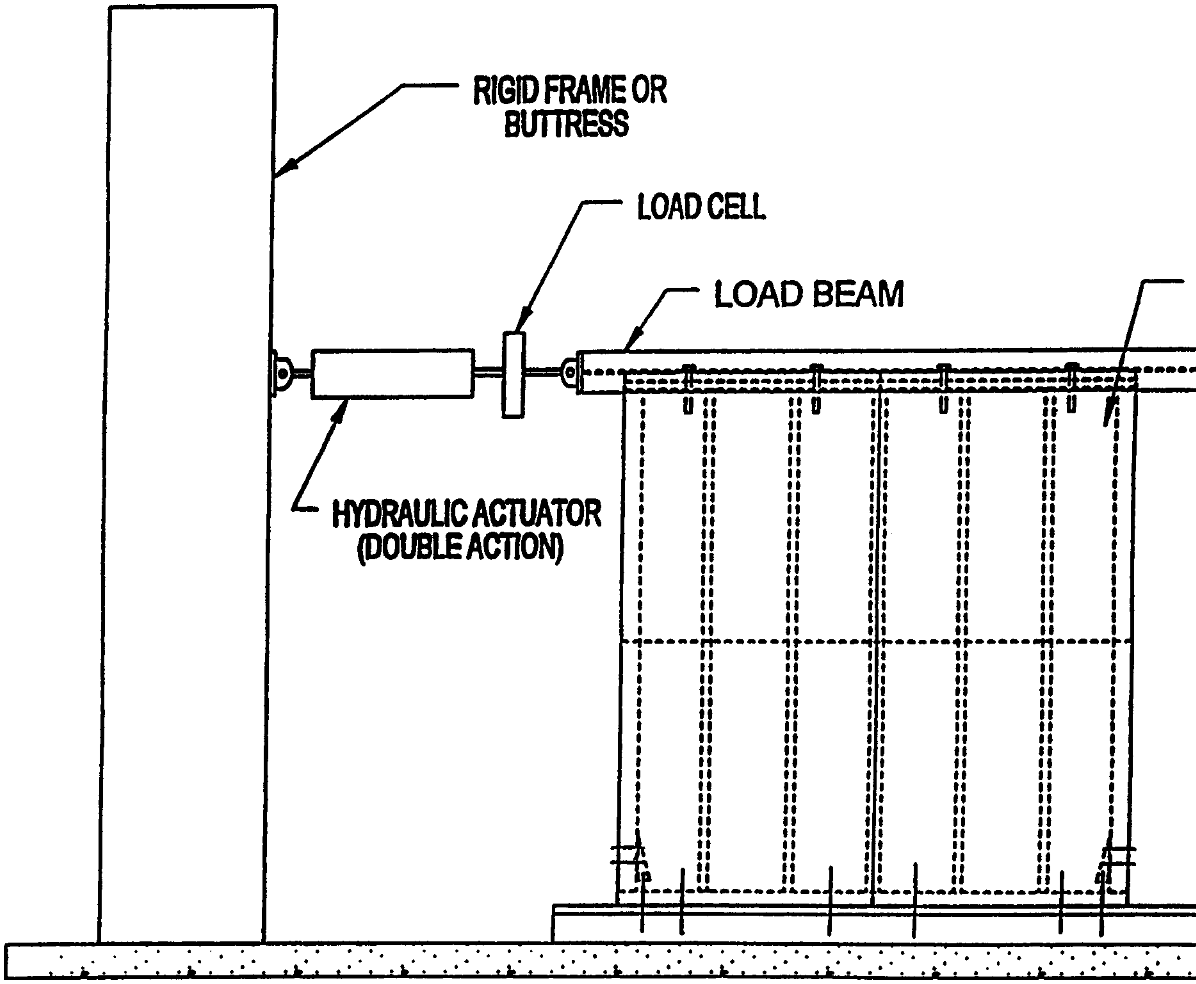

FIG. ~~7~~ 4 Test Setup for Cyclic Load Shear Wall Tests

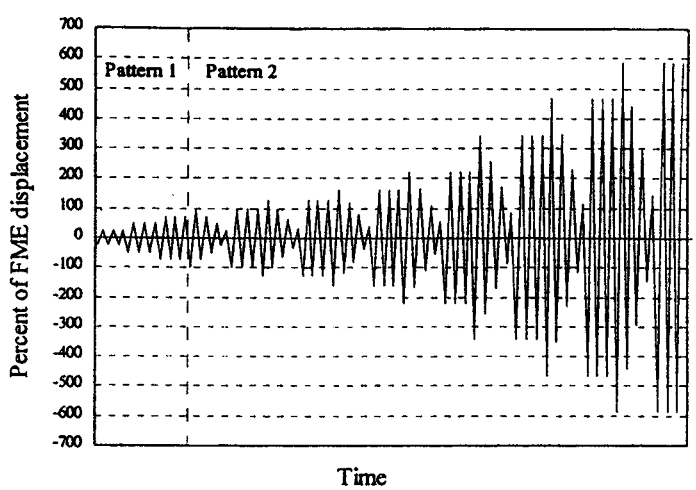

FIG. 5 Sequential-Phased Displacement Cyclic Displacement Schedule (Method A)

$$G' = \frac{P}{\Delta} \times \frac{H}{L} \quad (3)$$

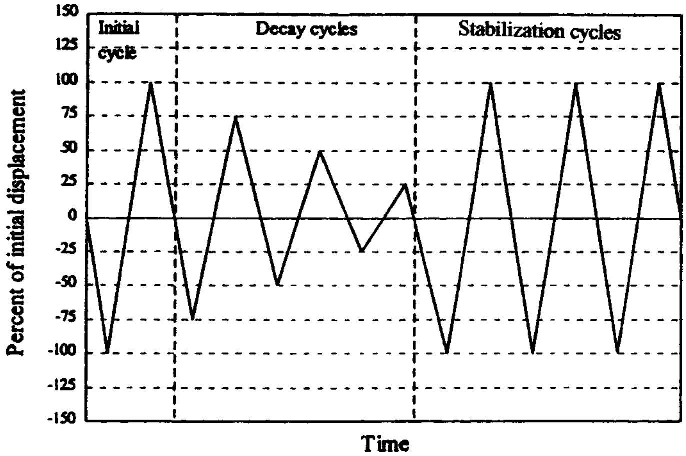

FIG. 6 Single Phase of Pattern 2 (Method A)

TABLE 1 Method A—Amplitudes of Initial Cycles

Pattern	Phase	Amplitude of Initial Cycle % FME
1	1	25
	2	50
	3	75
2	4	100
	5	5µ
	6	10µ
	7	20µ
	8	40µ
	9	60µ
	10	80µ
	11	100µ
	12	Additional amplitudes of 20µ (until wall failure)

TABLE 2 Method B—Amplitudes of the Reversed Cycles

Pattern	Step	Minimum No. of Cycles	Amplitude, % Δ_u
1	1	1	1.25
	2	1	2.5
	3	1	5
	4	1	7.5
	5	1	10
2	6	3	20
	7	3	40
	8	3	60
	9	3	80
	10	3	100
	11	3	Additional increments of 20 (until wall failure)

where:

G' = shear modulus of the wall obtained from test (includes shear deformation for the connection system), lbf/in. (or N/m); defines the secant to the force displacement curve at specified wall displacements.
P = lateral shear force measured at the top edge of the wall, lbf (or N).
Δ = displacement of the top edge of the wall based on test, in. (or m). This includes both the shear deflection of the sheathing material and its connections, and the contribution of the shear and holddown connection systems.
H = height of shear wall, ft (or m).
L = length of shear wall, ft (or m).

9.1.4 From each of the envelope curves, calculate the ductility factors, µ, as described in 3.~~1~~2. If the shear stiffness (shear modulus) at 0.4 P_{peak} is greater than that at P_{peak}, generate the EEEP curves corresponding to the negative and positive envelope curves, as described in 3.~~1~~2.3. Otherwise, the FME and the ultimate displacement shall be determined directly from the envelope curves. Calculate mean values of ductility factors, displacement, shear forces and shear modulus at the yield limit state and strength limit state.

10. Report

10.1 The report shall include the following information:

10.1.1 Date of the test and of report.

10.1.2 Names of the test sponsors and test agency and their locations.

10.1.3 Identification of the wall assembly (test number, etc.).

10.1.4 Detailed description of the wall assembly, including the following:

10.1.4.1 Dimensions of wall assembly.

10.1.4.2 Details of the physical characteristics or structural design, or both, of the wall assembly, including, if applicable, the type, spacing, and edge distance of fasteners attaching sheathing to framing.

10.1.4.3 Details of attachment of the wall assembly in the test fixture.

10.1.4.4 Location of load application and load cell, strain gages, deflection gages, and other items for test as applicable.

10.1.4.5 Description of construction materials (for example, material type and grade, thickness, yield point, tensile strength, compressive strength, density, moisture content, manufacturer of components used, source of supply, dimensions, model, type, and other pertinent information, etc., as appropriate for materials used).

10.1.4.6 Drawing showing plan, elevation, principal cross section, and other details as needed for description of the wall assembly (see 10.1.4.1-10.1.4.5).

10.1.4.7 Description of general ambient conditions include the following:

(1) At construction;

(2) During curing or seasoning, if applicable (including elapsed time from construction to test); and

(3) At test.

10.1.4.8 Modifications made on the wall assembly during testing.

10.1.4.9 Description of any noted defects existing in the wall assembly prior to test.

10.1.5 Description of the test, including a statement that the test or tests were conducted in accordance with this method or otherwise describing any deviations from the test method.

10.1.6 Summary of results, including:

10.1.6.1 Hysteresis loops (racking force vs. displacement at the top of the wall) for every wall assembly tested.

10.1.6.2 Complete record (table or plot) of individual displacements required to be measured in 7.6 and 6.2.

10.1.6.3 Maximum shear strength (V_{peak}) and stabilized shear strength ($V_{peakstab}$) from tests of identical wall assemblies (9.1.1).

10.1.6.4 As-tested and mean values of P, Δ and G' at FME and strength limit state in accordance with 9.1.2 and 9.1.3.

10.1.6.5 EEEP response curve developed from the mean displacement/shear forces at yield limit state and failure limit state, if applicable (see 9.1.3).

10.1.7 Description of failure modes and any behavior change and significant events, for each test.

10.1.8 Photographs of the wall assembly, particularly those depicting conditions that cannot otherwise be easily described in the report text, such as failure modes and crack patterns.

10.1.9 Appendix (if needed) that includes all data not specifically required by test results. Include special observations for building code approvals.

10.1.10 Signatures of responsible persons are in accordance with Practice E 575.

11. Precision and Bias

11.1 No statement on the precision and bias is offered due to the numerous individual elements that comprise the wall and the small number of replicate specimens tested. A generally accepted method for determining precision and bias is currently unavailable.

12. Keywords

12.1 cyclic loads; earthquake; framed walls; racking loads; rigid support; shear displacement; shear stiffness; shear strength

APPENDIXES

(Nonmandatory Information)

X1. DETERMINATION OF FIRST MAJOR EVENT

X1.1 The first major event (FME) is the first significant limit state that occurs during the test. The limit state in turn denotes an event marking phase change between two behavior states. As noted in Section 8.2.1, the FME can be determined from preliminary load cyclic tests on an identical wall assembly. If the first estimate is inappropriate, the data obtained can be revised for the subsequent tests. The following estimates offer guidance for a typical 96.0-in. (2438-mm) wall.

X1.1.1 *Wood-Framed Walls with Wood Structural Panel Sheathing*—Aspect ratios of 2:1 or less, FME = 0.8 in. (20 mm); aspect ratio of 4:1, FME = 1.2 in. (31 mm).

X1.1.2 *Wood-Framed Walls with Gypsum Sheathing*—Aspect ratios of 2:1 or less, FME = 0.25 in. (6.4 mm).

X2. SELECTION OF CYCLING METHOD

X2.1 *Selection of Method of A Versus Method B*

X2.1.1 Method A is a sequential phased displacement pattern that exhibits decay cycles between the steps in the loading pattern. These decay cycles provide information on whether there is a lower bound in displacement required to produce hysteretic energy dissipation. An example where a lower bound displacement causing hysteretic energy dissipation may occur would be a bolted connection through an over-drilled hole. Method A may be applicable to systems when FME is the yield limit state or for testing slack systems to determine a lower bound displacement causing hysteretic energy dissipation. Method B is a ramped displacement phase that bases the cycles on the percentage of an ultimate displacement determined through static tests. Method B may be more applicable to systems that exhibit linear elastic behavior where FME is the strength limit state. If the ratio of Δ_u and FME is less than three, Method B may be preferable.

REFERENCES

(**1**) Chopra, A.K., 1995, "Dynamics of Structures—Theory and Applications to Earthquake Engineering, Prentice-Hall, Inc., Englewood Cliffs, NJ 07632.

(**2**) Porter, M.L., 1987, Sequential Phased Displacement (SPD) Procedure for TCCMAR Testing," Proceedings of Third Meeting of the Joint Technical Coordinating Committee on Masonry Research, U.S./Japan Coordinated Earthquake Research Program, Tomamu, Japan.

(**3**) Foliente, G.C., 1994, "Analysis, Design, and Testing of Timber Structures Under Seismic Loads," Proceedings of Research Needs Workshop, available from University of California–Berkeley, Forest Products Laboratory, 1301 South 46th St., Richmond, CA 94804.

(**4**) White, M.W., and Dolan, J.D., 1995, "Nonlinear Shear-Wall Analysis," ASCE *Journal of Structural Engineering* , November 1995, American Society of Civil Engineers, New York, NY 10017–2398.

(**5**) Structural Engineers Association of Southern California, 1997, Standard Method of Cyclic Reverse Load Tests for Shear Resistance of Framed Walls for Buildings. 5360 Workman Mill Road, Whittier, California 90601.

(**6**) Park, R., 1989, "Evaluation of Ductility of Structural & Structural Assemblages from Laboratory Testing, Bulletin of the New Zealand Society for Earthquake Engineering, Vol 22, No. 3, September 1989, New Zealand.