STRUCTURAL ENGINEERS ASSOCIATION OF SOUTHERN CALIFORNIA

A Non-Profit California Corporation

5360 WORKMAN MILL ROAD
WHITTIER, CALIFORNIA 90601

DONALD H. GILBERT
EXECUTIVE DIRECTOR
(562) 908-6131
Fax: (562) 692-3425

- **Standard Method of Cyclic (Reversed) Load Test for Shear Resistance of Framed Walls for Buildings**
  Dated August 1, 1996
  Revised January 20, 1997 and Sept. 9, 1997

- **Standard Method of Cyclic (Reversed) Load Test of Structural Connector of Sub-assembly**
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  - **Commentary on Standard Method of Cyclic (Reversed) Load Test of Structural Connector of Sub-assembly**
    Dated February 20, 1997

- **Standard Method of Cyclic Load Test for Anchors in Concrete or Grouted Masonry**
  Dated August 1, 1997
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  - **Commentary Standard Method of Cyclic Load Test for Anchors in Concrete or Grouted Masonry**
    Dated April 30, 1997

Developed by

Structural Engineers Association of Southern California Ad Hoc Committee
Testing Standards for Structural Systems and Components
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Standard Method of

Cyclic (Reversed) Load Test for Shear Resistance of Framed Walls for Buildings

Based on ASTM Standard E 564-76 (Reapproved 1984)

1. Scope

1.1 This method is designed to evaluate the shear stiffness and shear strength of a typical section of a framed wall *system*, including its shear connections and hold-down connectors, under cyclic (reversed) load conditions.

1.2 *This method may involve hazardous materials, operations, and equipment. This method does not purport to address all of the safety problems associated with its use. It is the responsibility of whomever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.3 Tests shall be performed by a third party testing laboratory licensed by the City of Los Angeles. Tests shall be conducted under the direction and control of a Civil or Structural Engineer who is independent of the proponent and the testing laboratory, and is licensed by the State of California.

2. Referenced ASTM Documents

D 2395 Standard Test Methods for Specific Gravity of Wood and Wood-Base Materials

D 4442 Standard Test Methods for Direct Moisture Content Measurement of Wood and Wood-Base Materials

D 4444 Standard Test Methods for Use and Calibration of Hand-Held Moisture Meters

3. Definitions

3.1 *First Major Event* - The first significant limit state to occur (see Limit State).

3.2 *Limit State* - An event which marks the demarcation between two behavior states, at which time some structural behavior of the element or system is altered significantly.

3.3 *Yield Limit State* - The point in the force-displacement relationship where the difference in the forces in the first and fourth cycle, at the same displacement, does not exceed 5%.

3.4 *Strength Limit State* - The point in the force-displacement relationship corresponding to the maximum displacement for the peak force attained by the element or system.

3.5 *Useful Displacement* - The displacement where the strength limit state occurs.

4. Summary of Method

4.1 The cyclic shear stiffness and shear strength 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 or displacement 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 (Sec. 7.6).

5. Wall Assembly

5.1 *General* - The 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 Sec. 5.2.

5.2 *Connections* - The performance of the wall is influenced by the type and spacing of the shear connections and hold-down connectors to the rigid base. These connections shall be sized to resist the anticipated maximum load level. The contribution of the displacements of these connections to the total displacement of the wall assembly, at the strength limit state, shall be limited to 0.15% of the wall height.

5.3 *Frame Requirements* - The frame of the wall assembly shall be comprised of materials to be used in the actual building construction. The connections of these members shall be consistent with those intended in actual building construction.

5.3.1 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 hours passes between these operations (ASTM D 4442, Method A or B; or ASTM D 4444, Method A or B); and specific gravity of the lumber (ASTM D 2395, Method A).

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

5.4 *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 (Fig. 1).

6. Test Setup

6.1 The wall assembly shall be tested such that all elements and sheathing surfaces are observed during the test. The bottom of the frame shall be attached to a rigid base with shear connections as specified in Sec. 5.2. 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.

7. Procedure

7.1 *Number of Tests* - Test a minimum of two identical wall assemblies to determine the shear stiffness and shear strength of a given construction. If the 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 three walls tested. If only two tests are conducted, use the mean value.

7.2 Apply racking shear load horizontally to the top of the wall assembly along the axis of the frame (Fig. 2). A programmable double-acting hydraulic actuator with an integral load cell is suggested for conducting the tests. The cyclic displacement of the actuator shall be controlled to follow a cyclic sequential phased displacement procedure described in Fig. 3 and Table 1.

7.3 The increments selected for the sequential phased displacement (SPD) procedure are based on the First Major Event (FME) (Sec. 3). FME can be determined from preliminary cyclic load tests on an identical wall assembly.

7.4 The test loading procedure shall be per Fig. 3 and Table 1. Basically, the loading procedure consists of applying three cycles of fully-reversing displacement, at each displacement increment representing 25%, 50% and 75% of FME. Then, wall displacement is increased for one cycle to 100% of FME. Next, "decay" cycles of displacement for one cycle each at 75%, 50% and 25% of maximum displacement (e.g., 100% of FME) are applied, followed by three cycles of displacement at maximum displacement (100% FME), to stabilize the force-displacement response of the wall. Then, the next increment of increased displacement (125% of FME) is applied, followed by similar decay and stabilization cycles. The incremental force-displacement and decay cycles shall be continued to 150%, 175%, 200%, 250%, 300%, 350%, and 400% of FME, or until the applied force diminishes to 25% of the strength limit state.

7.5 Wall displacement shall be input to a controller to control the actuator displacement. The cyclic frequency shall be a maximum of 1.0 Hz (one cycle per second) to avoid inertial effects of the mass of the wall and test fixture hardware during cyclic loading, which could affect system response to cyclic loading. During later stages of the cyclic loading sequence, the cyclic frequency may be slowed to 0.2 Hz to properly control the hydraulic system with the instrument displacement input.

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

7.6.1 Horizontal displacement of the wall at the top plate.

7.6.2 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 face of the post to which the hold-down connector is installed, and located in the plane of the hold-down connector base, if applicable.

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

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

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

8. Calculation

8.1 Determine mean values resulting from tests of identical wall assemblies (Sec. 7.1). Calculate the following information from these tests:

8.1.1 *Maximum Shear Strength* - Determine the maximum shear strength, *Smax*, as follows:

$$S_{max} = \frac{P_{max}}{L}$$

where:

Smax	=	maximum shear strength, lbf/ft (or N/m)
Pmax	=	average of absolute value of strength limit states, lbf (or N)
L	=	length of shear wall, ft. (or m).

8.1.2 *Shear Stiffness* - Determine the shear stiffness on the basis of applied load at specified reference displacement levels, for use in displacement calculations.

8.1.2.1 From the hysteresis loops for both positive and negative cycles of displacement recorded during the cyclic tests, compute the shear modulus,G', at the yield limit state and strength limit state (Sec. 3.3 and 3.4) as follows:

$$G' = \frac{P}{\Delta} \times \frac{H}{L}$$

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 hold-down connection systems.
H	=	height of shear wall, ft (or m)
L	=	length of shear wall, ft (or m)

8.1.3 Calculate mean values for displacement, shear forces and shear modulus at the yield limit state and strength limit state as determined in Sec. 8.1.2.1.

8.1.4 Establish a bilinear force-displacement response that passes through the origin and the mean displacement/shear forces at yield limit state and strength limit state (Sec. 8.1.3), as shown in Figure 4.

9. Report

9.1 The report shall include the following information:

9.1.1 Date of the test and of report.

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

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

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

9.1.4.1 Dimensions of wall assembly.

9.1.4.2 Details of the physical characteristics or structural design, or both, of the wall assembly.

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

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

9.1.4.5 Description of construction materials (e.g., 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).

9.1.4.6 Drawing showing plan, elevation, principal cross section, plus other sections as needed for description of the wall assembly (Sec. 9.1.4.1 - 9.1.4.5).

9.1.4.7 Description of general ambient conditions:

(a) At construction.

(b) During curing or seasoning, if applicable (including elapsed time from construction to test).

(c) At test.

9.1.4.8 Modifications made on the wall assembly during testing.

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

9.1.5 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.

9.1.6 Summary of results, including:

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

9.1.6.2 Complete record (table or plot) of individual displacements required to be measured in Sec. 7.6 and 5.2.

9.1.6.3 Maximum shear strength (Smax) from tests of identical wall assemblies (Sec. 8.1.1).

9.1.6.4 As-tested and mean values of P, Δ and G' at yield limit state and strength limit state (Sec. 8.1.2.1 and 8.1.3).

9.1.6.5 Bi-linear force-displacement response developed from the mean displacement/ shear forces at yield limit state and strength limit state (Sec. 8.1.4).

9.1.7 List of observers.

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

9.1.9 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.

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

9.1.11 Signatures of responsible persons.

10. Bibliography

Chopra, A.K. 1995. Dynamics of Structures - Theory and Applications to Earthquake Engineering. Prentice-Hall, Inc., Englewood Cliffs, NJ 07632.

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.

Foliente, G.C. 1994. Analysis, Design and Testing of Timber Structures Under Seismic Loads. Proceedings of Research Needs Workshop. Available from University of Califomia - Berkeley, Forest Products Laboratory, 1301 South 46th St., Richmond, CA 94804.

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.

Table 1. - Sequential phased displacement load procedure for shear walls

Cycle No.	% FME
0	0
1	25
2	25
3	25
4	50
5	50
6	50
7	75
8	75
9	75
10	100
11	75
12	50
13	25
14	100
15	100
16	100
17	125
18	94
19	63
20	31
21	125
22	125
23	125
24	150
25	113
26	75
27	38
28	150
29	150
30	150
31	175
32	131
33	88
34	44
35	175
36	175
37	175

Cycle No.	% FME
38	200
39	150
40	100
41	50
42	200
43	200
44	200
45	250
46	188
47	125
48	63
49	250
50	250
51	250
52	300
53	225
54	150
55	75
56	300
57	300
58	300
59	350
60	263
61	175
62	88
63	350
64	350
65	350
66	400
67	300
68	200
69	100
70	400
71	400
72	400

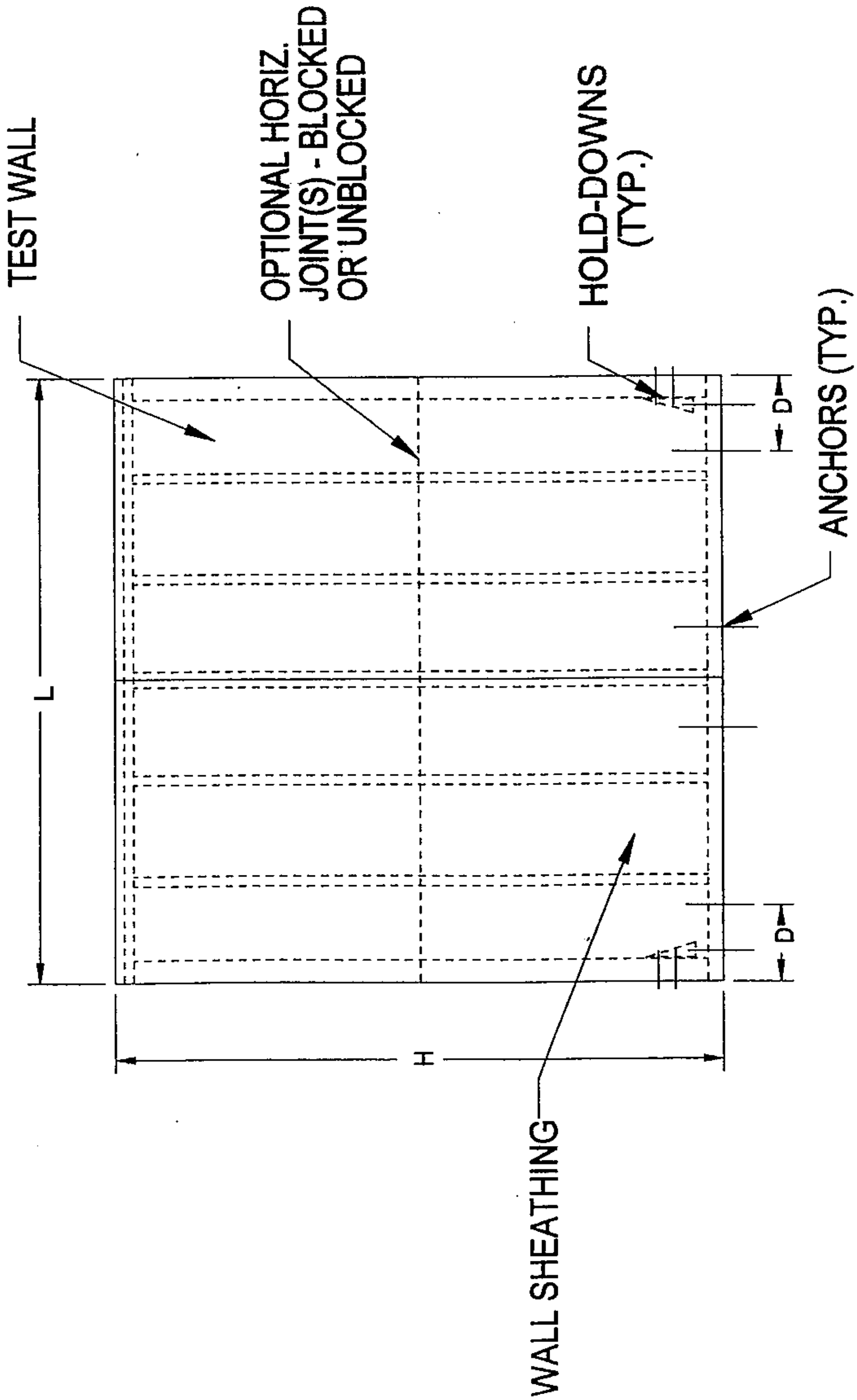

Figure 1.- Cyclic load shear wall test specimen

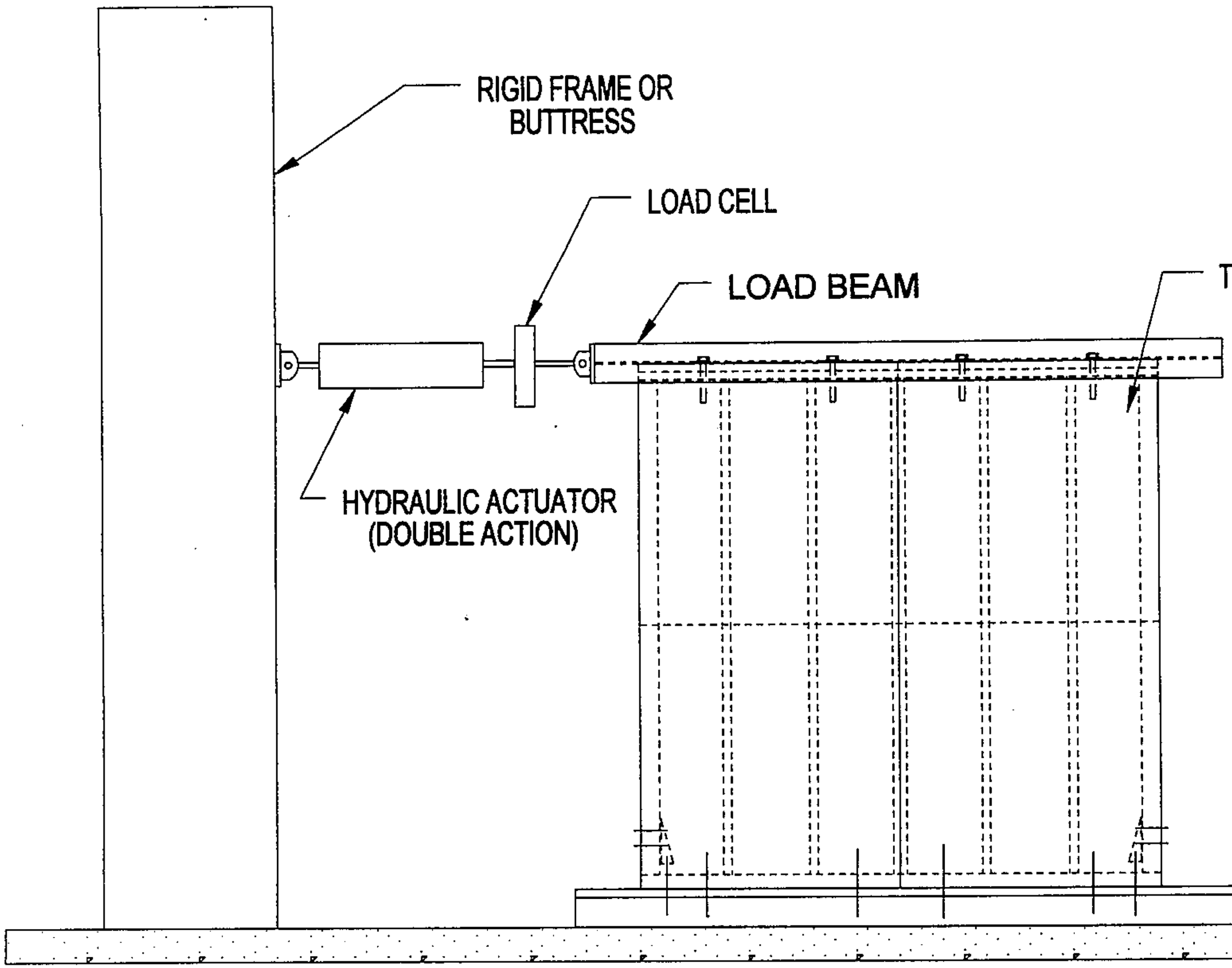

Figure 2. - Test setup for cyclic load shear wall tests

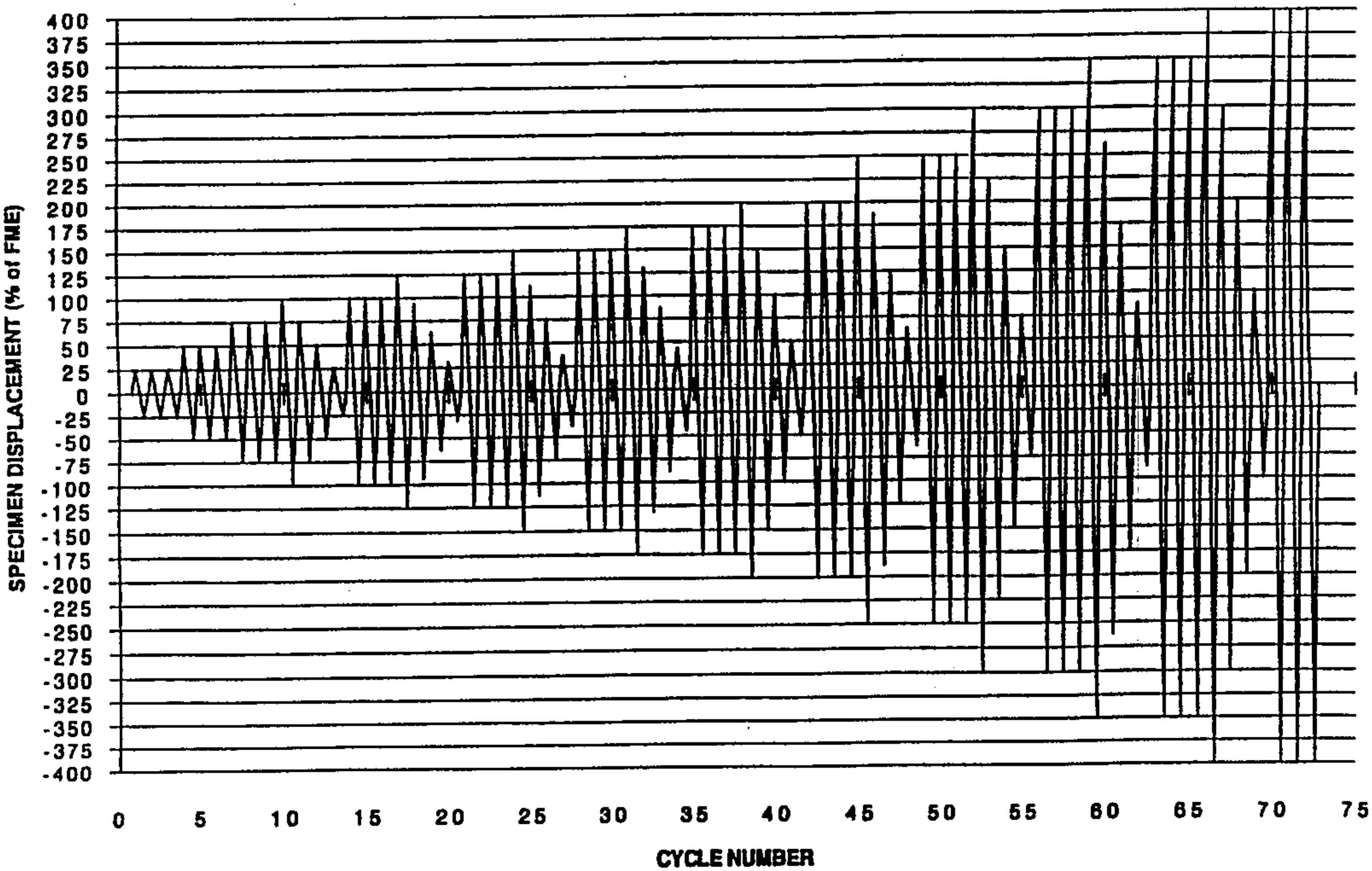

Figure 3. - Sequential phased displacement (SPD) procedure for shear walls

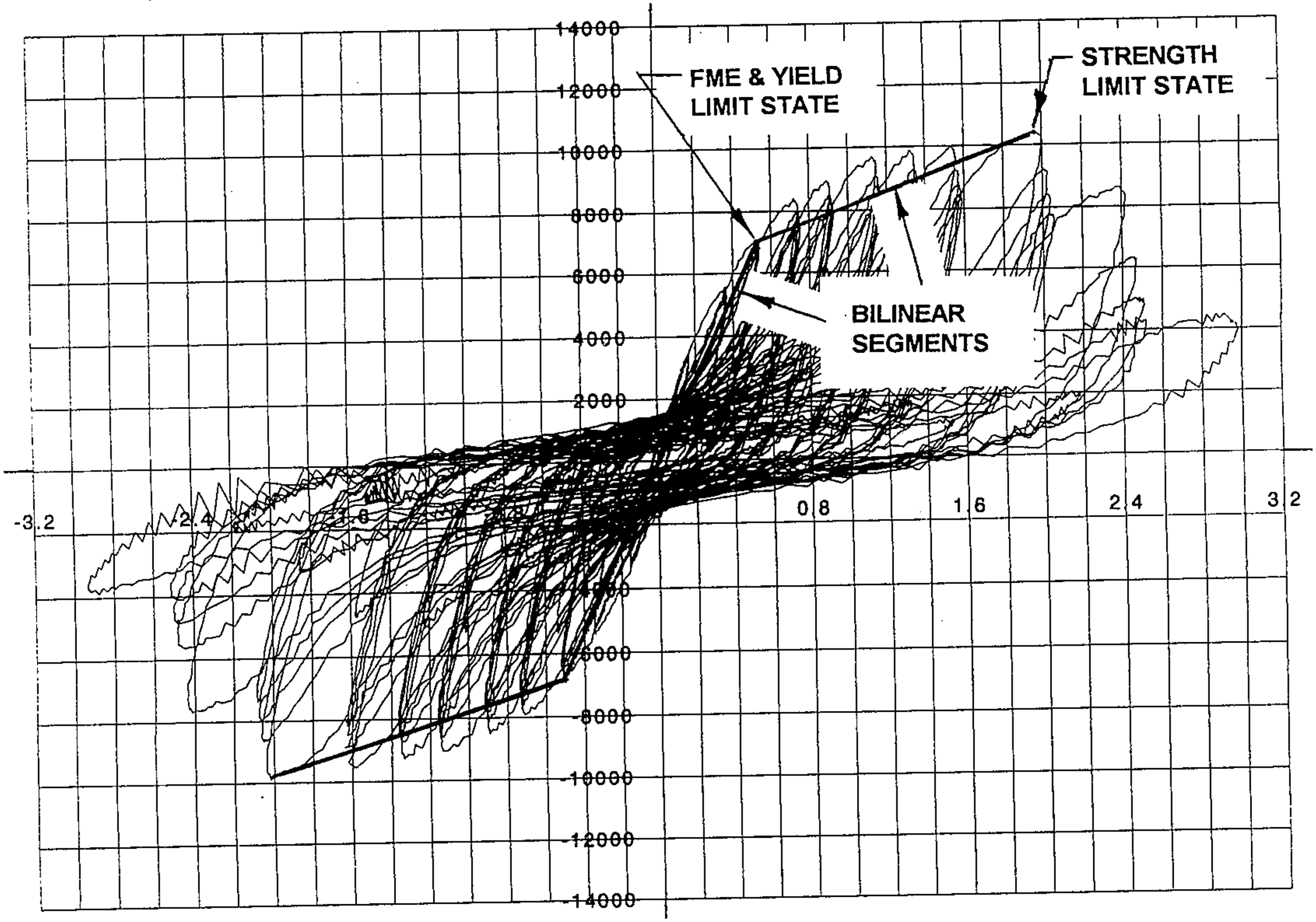

Figure 4. - Force-displacement curve for typical cyclic load shear wall test

Standard Method of Cyclic (Reversed) Load Test of Structural Connector or Sub-assembly

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R. Wollmershauser
Dr. Yan Xiao
Chi Yang
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Standard Method of Cyclic (Reversed) Load Test of Structural Connector or Sub-assembly

1. Scope

1.1 This test method evaluates the stiffness and strength of structural connectors and sub-assemblies under cyclic (reversed) loading.

1.2 These tests are not applicable to shear or tension anchors embedded in concrete. Other tests are required for evaluating connector fasteners or anchor bolts to concrete or reinforced masonry.

1.3 Tests shall be performed by a third party testing laboratory licenced by the City of Los Angeles. Tests shall be conducted under the direction and control of a Civil or Structural Engineer who is independent of the proponent and the testing laboratory and is licensed by the State of California.

2. Reference Documents

2.1 City of Los Angeles Building Code.

2.2 Standard Method of Cyclic Load Test for Anchors in Concrete or Grouted Masonry.

2.3 Standard Method of Cyclic (Reversed) Load Test for Shear Resistance of Framed Walls for Buildings.

3. Definitions

3.1 **First Major Event (FME)** - The first significant limit state to occur (see Limit State).

3.2 **Limit State** - An event which marks the demarcation between two behavior states, at which time some structural behavior of an element or system is altered significantly.

3.3 **Strength Limit State (SLS)** - The maximum strength attained by the element or system.

3.4 **Useful Displacement** - The displacement at which the Strength Limit State occurs.

3.5 **Yield Limit State (YLS)** - The point in the load/displacement relationship where non-linear behavior begins.

4. Summary of Method

4.1 The cyclic stiffness and strength of the connector or sub-assembly are determined by subjecting the test specimen to cyclic loading defined in 7.4.

4.2 The effects of all eccentricities and restraints imposed by the connector on the framing member or system for which it is intended, shall be measured and reported.

4.3 The effects of the properties of the materials in the total assembly for which the connector is intended shall be incorporated in the test specimen. Properties such as wood shrinkage shall be considered. Refer to commentary.

4.4 The test shall provide data on the behavior and modes of failure of the connector and members to which it is connected.

5. Test Specimen

5.1 General. The test specimen consists of the connector and connecting sub-assembly framing elements, installed in the manner that it is intended to be used. Framing materials to which it is connected shall be of the same type, description, specification and dimension as intended for actual building construction.

5.2 Materials. Specifications for all materials used in the test specimen shall be given. All materials used shall be those listed in the applicable code.

5.3 The fabricated holes in the connector shall be sized and drilled per code for the bolts, screws or nails to be used.

5.4 Installation. The connector shall be installed and fastened in complete conformance with the City of Los Angeles Building Code, the connector and sub-assembly design and specifications, or the manufacturer's written specifications and instructions where applicable. The quality control procedures for the installation of the test specimen shall be the same as those used for actual building construction. The installation shall be continuously observed by the responsible testing laboratory.

6. Test Setup

6.1 The test apparatus shall ensure that all potential failure modes can occur without interference or unplanned restraint. The test specimen shall be instrumented to measure three-dimensional displacements of the connector and sub-assembly members.

6.2 Restraining forces, if provided by restraints incorporated in the test apparatus, shall be measured and reported.

6.3 Tension forces in bolts due to connector and framing member eccentricities shall be measured and reported

6.4 Refer to commentary for discussions of possible test apparatus setups for various connector types.

7. Procedure

7.1 A minimum of three identical test specimens shall be tested to measure the stiffness and strength of the connector or sub-assembly. If the Coefficient of Variance exceeds 5%, then two additional identical tests shall be performed and reported.

7.2 The test setup shall ensure that all the potential failure areas are clear for observation during the test.

7.3 The increments selected for the cyclic (reversed) loading procedure shall be based on the First Major Event (FME). The FME for the test specimen is the lessor of the FME for the (steel) connector or the (wood or steel) element to which it is connected. Alternatively the FME may be determined from preliminary cyclic load tests on an identical test specimen.

7.4 Test procedure. The general test procedure consists of applying three cycles of fully reversing force at each force increment representing 20%, 40%, 60%, 80%, 100%, 120%, 140%, 160%, 180% and 200% of FME, or until the applied force diminishes to 20% of the strength limit state.

7.5 Force increments shall be input to a controller to control the actuator. The cyclic frequency shall be a maximum of 1.0 Hz (one cycle per second). The test frequency shall avoid inertial effects related to the mass of the test apparatus or test specimen which could affect the measured response to the cyclic loading.

7.6 Instrumentation.

7.6.1 Forces shall be measured with load cells capable of measuring forces to within 1% of the FME at a minimum sampling rate of 100 reading per cycle.

7.6.2 Displacements shall be measured with linear variable transducers, or other suitable devices. The resolution of the linear transducers shall be .001 inches or 1% of the expected total range of the measured displacement whichever is greater (coarser).

7.6.3 The following instrumentation shall be provided for measuring displacements and forces. In-line shall mean along the line of the primary direction of the force for which the connector is intended for use.

.1 Actuator force at the end of connected member remote from the connector.

.2 In-line and perpendicular displacements at the connected end of the connected member. The point of measurement shall be at the contact point between the connector and the member closest to the connected end of the member.

.3 Displacements of the connected member relative to the connector.

.4 Forces in bolts, perpendicular to the in-line force, required for equilibrium due to eccentricity from the centerline of the connected member to the centerline of the element delivering the force to the connector.

.5 Forces and displacements provided by restraints incorporated in the test apparatus.

8. Calculation

8.1 Determine mean values resulting from tests of identical test specimens (Sec. 7.1). Determine the following:

Load Displacement Curves.
Yield Limit State (YLS), tension and compression.
Strength Limit State (SLS), tension and compression.

8.2 Load displacement curves.

8.2.1 From the hysteresis loops recorded during the cyclic tests, determine a complete (tension and compression) "backbone curve" by producing the line of best fit through the maximum force recorded and its associated displacement. Backbone curves shall be developed for each specimen tested.

8.2.2 Using the curves produced under Sec 8.2.1, develop a single average force-displacement curve to describe the behavior of the tested specimens.

8.3 **YLS**: Determine the tension and compression YLS from the average force-displacement curve developed under Sec. 8.2.2. Report the corresponding displacements.

8.4 **SLS**: Using the back bone curves developed under Sec. 8.2.1 determine the tension and compression SLS for each test specimen. Calculate the average tension SLS and compression SLS and the corresponding standard deviations. Report the corresponding displacements.

8.5 Calculate:

.1 The strength of the connector by the code Allowable Stress Method.

.2 The strength of the connector by the code Strength Method.

8.6 Using the average force-displacement curve developed under Sec. 8.2.2, determine the displacements corresponding to the following tension forces.

.1 Strength of connector calculated by the code Allowable Stress Method.

.2 Strength of connector calculated by the code Strength Method.

9. Report

The report shall include the following information.

9.1 Date of test and report.

9.2 Name of the test sponsors, testing agency and the licensed engineer directing and controlling the test per 1.3.

9.3 Components with which the connector is intended for use.

This test method does not address the strength of the members or elements intended to be used with the connector. The report shall caution that the strength of such elements needs to be assessed independently.

Refer to commentary.

9.4 Detailed description of the test specimen, including the following.

9.4.1 Complete connector and sub-assembly design and specifications, and the manufacturer's written specifications and instructions for installation, where applicable. These shall be provided in an Appendix to the report.

9.4.2 Connector installation. Certify that installation was in accordance with specifications and instructions and in accordance with the quality control procedures used for actual building construction, based on the continuous observation by the licensed engineer.

9.4.3 Note any modifications made to the connector, the assembly or the method of installation during the fabrication of the test specimens.

9.5 Description of the test.

9.5.1 General description of the test specimen during the test.

9.5.2 Note any modifications made to the test specimen, the test apparatus, or to the testing procedures made during the test.

9.5.3 Detailed description of the modes of failure. This shall include photographs of representative conditions and photographs of special conditions that are observed in specific tests.

9.6 Summary of results, including:

9.6.1 Calculated strengths and corresponding displacements for the connector determined per 8.5 and 8.6.

9.6.2 Average force-displacement relationship developed under Sec. 8.2.2 for all actions measured during the test that depict the complete behavior of the connector or sub-assembly. When restraints are used the curves shall include the relationships between the applied forces, the restraint forces, and the displacements.

9.6.3 Values of **YLS** (tension and compression) and corresponding displacements calculated under Sec 8.3.

9.6.4 Values of **SLS** (tension and compression), corresponding standard deviations and corresponding displacements calculated under Sec 8.4.

9.7 List of observers.

9.8 Photographs with captions and references to appropriate text.

9.9 Stamp and signature of licensed engineer per 1.3.

Appendix: References

Appendix: Raw data.

Appendix: Connector and sub-assembly design and specifications, and installation instructions.

Appendix: Manufacturer's catalogue listing and recommended use details, including items outlined in 9.3. This shall be complete and exactly as it will be published.

Commentary on Standard Method of Cyclic (Reversed) Load Test of Structural Connector or Sub-Assembly

C1 Scope

C1.1 This test method is intended for testing a connector or sub-assembly. A connector is a manufactured or fabricated device that connects parts of a structural system. The materials connected could be similar or dissimilar. In many instances the materials that connect the manufactured or fabricated device to adjacent parts of the structural system may be materials that have code strength values. See also comment C5.2. The purpose of tests conducted under this standard is to determine the stiffness or elongation of the connector or sub-assembly at a limit state such as yield and strength limit states. A sub-assembly is part of the structural system or assembly of materials that is not expected to contribute to the ductility of the system. In general, a sub-assembly is more difficult to analyze for elongation than a connector.

C1.2 A method for testing anchors embedded in concrete or masonry is given in a separate document. Refer to "Standard Method of Cyclic (Reversed) Load Test for Anchors in Concrete or Grouted Masonry."

C1.3 The testing laboratory is required to be licensed by the public agency or jurisdiction. This testing laboratory could be operated and owned by the proponent of the connector. The licensing assures that the laboratory has a quality control program, adequate instrumentation and trained personnel. The testing program is under the direction and control of a licensed Engineer who is independent of the proponent and the testing laboratory. This engineer confirms equipment calibration and observes, directs and controls the testing and reporting of the results.

C2 Reference Documents - No commentary.

C3 Definitions

C3.1 The First Major Event (FME) is the point where the load-displacement behavior of the connector changes from near-linear to non-linear. The FME may be given as a displacement or strength. The FME is used only in the test program to determine the increments of loads that are applied during the test. The value of the FME can be estimated as described in Section 7.3. If the first estimate is inappropriate, the data obtained in the test is still valid and the value of the FME can be revised for subsequent tests. See also comment under C3.3.

C3.2 The Limit States that are common for connections are the Yield Limit State and the Strength Limit State. The Yield Limit State is commonly the First Major Event for a connector that is fabricated from steel.

C3.3 A Strength Limit State distinct from the Yield Limit State is only recognized if the test specimen undergoes at least 15 equal or increasing excursions into the non-linear zone.

C3.4 The useful displacement is measured at the Strength Limit State because at that point strength degradation begins.

C3.5 The Yield Limit State is generally not precisely defined by the test. It is the intersection point of a bilinear force-displacement envelope that is imposed on the static-hysteresis plots that were determined by the testing.

C4 Summary of Method

C4.1 No Commentary.

C4.2 Many connectors do not have a line of action without offsets. This causes moments and/or forces normal to the line of action in the connector and the connected members. The forces normal to the line of action shall be measured and reported. If a restraint separate from the connector is used in the testing setup to resist the effects of eccentricity in the anchorage, the forces in this restraint must be measured and reported.

C4.3 The test specimen shall represent the assembly as used. The relative stiffness of members used in the test shall be the same as described in the manufacturer's installation specifications. Wood shrinkage can leave gaps in the assembly if a method for accommodation of wood shrinkage is not provided for in the installation or manufacturing method. Gaps in the assembly representing those expected shall also be included in the test specimen.

C4.4 No Commentary.

C5 Test Specimen

C5.1 No Commentary.

C5.2 Materials listed in the code have assigned strength values, capacity reduction factors and similar attributes that enable the design engineer to calculate code acceptable strength. All material used for connectors must use these code prescribed materials in their manufacture, and compliance with the specification of code complying materials shall be reported.

C5.3 No Commentary.

C5.4 No Commentary.

C6 Test Setup

C6.1 The test apparatus shall not restrain twisting, sideways movement or moments in the connector or connecting members. All displacements caused by this behavior shall be measured and reported. All forces in supports caused by such behavior shall be measured and reported. For instance, if shear forces are caused in an anchor bolt in addition to tensile forces, such shear forces in the anchor bolt shall not be restrained and shall be measured.

C6.2 If a restraint to forces caused by eccentricities in the connector is a part of the connection, the displacement of the restraint and the forces in the restraint shall be measured and reported. Clamping of connectors to the test fixture may induce tension forces in the anchor bolts greater than the applied tensile force. These total tension forces in the anchor bolt shall be measured and reported.

C6.3 No Commentary.

C6.4 A connector that has eccentricity in the line of action between the applied load and the resistance to that load must be tested in a setup that allows the moment caused by the eccentricity to be transmitted exclusively to the member being connected. The out-of-line forces needed for equilibrium must be measured. Elongation due to eccentricities shall not be restrained. The end of the connector member with the eccentricity must not be restrained from movement in any direction. All movements shall be measured and reported.

Connectors may be used in different configurations. For example, hold-down type connectors may be attached to members restrained by plywood sheathing or to members that are not restrained. The testing must consider all intended use conditions. If sheathing restraint is included in the test of the connector, the effect on the sheathing must be determined and reported so that it can be included in the determination of other sheathing action used in the total system.

Some connectors may be used in configurations that have eccentricities in more than one direction or plane. The testing must consider all intended use conditions and report the effects of all eccentricities for the configurations intended.

Summing connector values for connectors used back to back on the same connected member using common bolts will not be allowed without demonstrating an appropriate field installation and quality control procedure. Common field practices employing bent bolts and/or back drilled holes to get alignment of the connector bolt holes will produce pairs of connectors with significantly different load-displacement behavior from that of a single connector.

C7 Procedure

C7.1 The intent is to obtain a representative expected strength and expected displacement from three identical test specimens. If the Coefficient of Variance exceeds 5 percent it indicates that the value of an expected strength has not been adequately determined and that additional tests are required.

C7.2 No Commentary.

C7.3 The First Major Event has been defined in C3.1. It may be the estimated yield or failure of a steel connector if yield is not expected. It may be the beginning of non linear slip of attachments such as nails, screws or bolts to the connected member. The load or displacement at the FME can be determined by calculation, reference to experimental research, or from preliminary cyclic testing.

C7.4 The range of force increments is intended to assure the Strength Limit State (SLS) is attained and that post-SLS behavior is determined. The rate of strength degradation is an important part of the test data. See also comment C3.3.

C7.5 No Commentary.

C7.6 No Commentary.

C8 Calculation

C8.1 No Commentary.

C8.2 Load displacement curves.

C8.2.1 The "backbone" curve is prepared by producing a curve through the minimum displacement point for each force increment. The second and third loading at each increment of force may cause increased displacement. These points will lie below the "backbone" curve.

C8.2.2 No Commentary.

C8.3 The Yield Limit State (YLS) is estimated from the best fit bilinear representation of the load-displacement plot. Generally a precise definition of the (YLS) does not exist. The (YLS) is used in the strength part of the seismic design process. Non-linear behavior of seismic resisting systems is expected during an earthquake but minimal non-linear response is expected from connectors. Capacity reduction factors are used to provide confidence that elastic behavior will occur when assumed in design.

C8.4 The Strength Limit State for connectors may be the same as or nearly equal to the Yield Limit State. The Strength Limit State represents the maximum force that may be transmitted to members by the connector or be compared to the inelastic Strength Limit States of members. Past seismic design practices have required the capacity of connectors to exceed the capacities of members or systems.

C8.5 The force calculated in the seismic design process uses the loading specified in the Code. This loading is not the expected seismic loading. However, this loading is used to calculate lateral displacements as the second part of the seismic design process. Multipliers of the displacements caused by code lateral forces are given in the Code for estimating probable lateral displacements. The strength of the connector is calculated by the allowable stress method or the code strength method when applicable. These are the strengths used in the design process. The experimental testing determines the displacements associated with these strengths for calculation of "code" displacements. The reported Yield Limit State and Strength Limit State provide the designer with data needed for compliance with code provisions, other than required code strength provisions.

C9 Report.

C9.1 No Commentary.

C9.2 No Commentary.

C9.3 This section is intended to warn the user as to conditions affecting the connector strength or stiffness related to the members with which the connector is intended for use. Items that require an independent assessment of strength include the following:

- The anchor attaching the connector must be designed to provide a capacity equal to or greater than the connector. This may be an anchor embedded in concrete and the requirements for edge distances, embedment, etc. must be considered separately.
- Members to which the connector is attached must be proportioned to resist all forces induced by connector eccentricities, etc. Strength and stiffness must be considered.
- Designs using connectors tested with restraints must independently provide the restraining forces. Designed restraint shall provide the same, or greater, stiffness as provided in the test.
- For wood members: consider grade, moisture content, actual dimensions, and the effects of holes or daps. Multiple members shall not be substituted for single solid members.
- For gauge metal members: consider connector attachment forces and actions due to connector eccentricity from the member centroid. Multiple member requirements and the required orientation and attachment between multiple members should be detailed in the sub-assembly design and specifications.

C9.4 No Commentary.

C9.5 No Commentary.

C9.6 No Commentary.

C9.7 No Commentary.

C9.8 No Commentary.

C9.9 No Commentary.

Standard Method of Cyclic (Reversed) Load Test for Anchors in Concrete or Grouted Masonry

Developed by

Structural Engineers Association of Southern California Ad Hoc Committee
Testing Standards for Structural Systems and Components
in conjunction with the City of Los Angeles

Committee Members:

Dr. Robin Shepherd, Chairman (1994 - 1995)
Graeme Dick, Chairman (1996 - 1997)
Robert Kazanjy, Secretary

Peter Anderson
Todd Borzi
Kent Carlson
Dr. Norman Cluley
Michael Cochran
John Coil
Al Commins
Mark Cooper
Vicki Covert
Maurice Davis
Dr. Dan Dolan
Richard J. Ernst
Brian Gerber
Robert Gregg
Frank Hoang
Mark Jensen
Albin Johnson
R. Kaczkowski
John Kariotis.
Kristen Keith
John Kurtz
Ray Leffner
Doc Nghiem
Ronald Ogawa
Nora Paller
Tom Porter
Robert Powell
Sandy Pringle
John Rose
Ben Schmid
Reynaud Serrette
Greg Severson
David Tyree
Javad Vakil
Tom Wall
Harry Wiewel
Yehuda Wolfson
R. Wollmershauser
Dr. Yan Xiao
Chi Yang
George Youdeem
Ed Zacher

Standard Method of Cyclic Load Test for Anchors in Concrete or Grouted Masonry

1. Scope

1.1 The purpose of these cyclic tests is to substantiate the use of anchors in resisting forces induced by earthquake motion. The test method evaluates proposed anchors for equivalence to code prescribed anchors. Limitations for fire rating, or long term creep are not considered in these tests.

1.2 Tests shall be performed by a third party testing laboratory licensed by the City of Los Angeles. Tests shall be conducted under the direction and control of a Civil or Structural Engineer who is independent of the proponent and testing laboratory and is licensed by the State of California.

2. Referenced Documents

2.1 City of Los Angeles Building Code.

2.2 ASTM E 488 Test Method for Strength of Anchors in Concrete and Masonry Elements

2.3 ASTM E 1512 Method of Testing Bond Performance of Adhesive-Bonded Anchors

2.4 Commentary

3. Definitions

3.1 **Adhesive anchor** (Proposed Anchor) - An adhesive anchor system refers to a threaded rod or insert, set in a predrilled hole containing chemical bonding compounds. Loads are transferred mainly by the bond of the adhesive to both the anchor and to the surrounding element along the side of the hole.

3.2 **Code Anchor** - A bolt or headed stud anchor complying with the code, that is cast-in-place into the concrete or masonry.

3.3 **Equivalence** - Equivalence is the condition where the Proposed Anchor achieves equal or less displacement versus load and has equal or greater peak load as the Code Anchor for equal diameter anchors.

3.4 **Expansion Anchor** (Proposed Anchor)- An Expansion anchor is a mechanical anchor which is set into a predrilled hole. Loads are transferred through a mechanically expanded system that exerts friction forces against the sides of the drilled hole.

3.5 **First Major Event (FME)** - The first significant limit state to occur (see Limit State).

3.6 **Limit State** - An event which marks the demarcation between two behavior states, at which time some structural behavior of the element or system is altered significantly.

3.7 **Proprietary Cast-in-Place Anchor** (Proposed Anchor) - Any manufactured cast-in-place device intended to replace a Code Anchor.

3.8 **Strength Limit State (SLS)** - The peak strength attained by the element or system.

3.9 **Structural Member** - The structural member refers to the concrete or masonry into which the anchor is to be embedded.

3.10 **Undercut Anchor** (Proposed Anchor)- An undercut anchor system refers to a steel mechanical anchor that is set into a predrilled hole that has been enlarged near the bottom of the hole. Loads are transferred mainly through bearing.

3.11 **Yield Limit State (YLS)** - The point in the load/displacement relationship where non-linear behavior begins.

4. Summary of Method

The Proposed Anchors are tested in tension or shear for comparison with Code Anchors that are installed in the same testing medium. The specimens tested shall represent the extremes of the range of anchor diameter and concrete or masonry strength for which approval is sought. Each combination of anchor diameter and concrete or masonry strength shall be tested at the minimum embedment for which approval is sought and the maximum embedment that does not cause failure in the body of the anchor. If the minimum embedment for which approval is sought causes failure in the body of the anchor, other embedments need not be tested. Extrapolation beyond the range of variables tested shall not be allowed.

4.1 The cyclic stiffness and strength of anchors are determined by subjecting the test assembly to cyclic loading as described in Section 7.

4.2 Tests shall provide data on failure in the concrete or masonry, or by pull-out of the anchors.

4.3 Tests shall be designed to examine the effect of the strength properties of the materials in which the anchors are embedded.

4.4 Tests shall be designed to examine the effects of the conditions affecting the anchors at the time of installation, such as temperature and/or overhead installation.

5. Test Specimens

5.1 **Testing Medium** - The structural member in which the anchor is embedded shall be constructed in the manner and with the materials permitted by the code.

5.1.1 **Concrete Mix Design** - Concrete may be any mix permitted by the code. The strength of the concrete shall be determined by concrete cylinder tests in accordance with the code to determine f'_c.

5.1.2 Masonry may be any assembly permitted by the code. The strength of the masonry shall be determined by prism tests in accordance with the code to determine f'_m.

5.1.3 **Strength determination** - The structural members must be aged a minimum of 21 days prior to installing the proposed anchors and beginning the tests. Strength tests shall be made at the beginning and at the end of the anchor tests. The average of the tests shall be used to determine the reported compressive strength. Tests shall be made on the anchors tested for equivalence within 5 days of each other.

5.2 **Anchor Installation.**

5.2.1 **Code Anchor** - Installation in masonry shall be in accordance with the code. The Code Anchor shall be held in place during placement of the concrete.

5.2.2 **Proposed Anchors** - The following apply:

5.2.2.1 Proposed Anchors shall comply with the manufacturer's specifications and tolerances. Proposed Anchors for testing shall be randomly taken from products intended for sale.

5.2.2.2 Proposed Anchors shall be installed in conformance with the manufacturer's written instructions. The manufacturer shall provide detailed information on physical, mechanical, and chemical properties of the anchor system. The installation shall be continuously observed by the licensed engineer described in Section 1.2.

5.2.2.3 Proposed Anchors that use temperature sensitive materials shall be installed in the positions intended for use. When approval is requested for overhead installation or at an angle greater than 15 degrees above horizontal, the anchors shall be installed in an overhead position. If the installation position requested is greater than 45 degrees from the downward direction, the anchors shall be installed at an angle of 15 degrees above horizontal. Testing shall be performed to show equivalence to anchors installed in the downward position. The air temperature and the structural member temperature shall, at the time of installation, be at the maximum temperature requested for approval. The anchors tested for comparison shall be tested for shear loading and tension loading. Any methods and/or procedures used for retaining the bonding material and supporting the weight of the embedments shall be fully described in the report.

5.2.2.4 Proposed Anchors that require a specified torque as part of the required installation procedure shall be installed as follows:

Anchors shall be installed at 100% of the minimum specified setting torque in accordance with the manufacturer's installation procedures. The anchor shall be left undisturbed for 48 hours after torquing.

5.2.3 For all anchors, nuts shall be loosened to a finger tight position before testing.

6. Test Setup

Apparatus used in tests shall conform to the requirements in Section 5 of ASTM E 488.

7. Procedure

7.1 Proposed Anchors shall be installed and tested in the structural member containing the Code Anchors.

7.2 Greater embedment of Proposed Anchors than used for Code Anchors may be used if this is necessary to provide equivalent performance to the Code Anchor.

7.3 A minimum of three specimens of each diameter, embedment, and type shall be tested.

7.4 The test setup shall ensure that the potential concrete cone failure zone area is not influenced by the test apparatus and is clear for observation during the test.

7.5 The increments selected for the sequential phased force (SPF) procedure shall be based on the First Major Event (FME). The FME may be determined from prior tests or preliminary cyclic load tests on an identical test assembly. The FME shall be chosen such that a minimum average of 20 but not less than 15 load cycles shall be applied before reaching 100% FME.

7.6 **Shear Tests** - The general test procedure consists of applying five cycles of fully reversing force at increments representing 25%, 50%, 75%, 100%, 125%, 150%, etc. of FME until reaching strength limit state.

7.7 **Tension Tests** - The test procedure described in Section 7.6 above shall be used without the reverse cycle.

7.8 Force increments shall be input to a controller to control the actuator. The cyclic frequency shall be a maximum of 1.0 Hz (one cycle per second). The test frequency shall avoid inertial effects related to the mass of the test rig or test assembly which could affect the measured response to the cyclic loading.

7.9 **Instrumentation** - Forces shall be measured with load cells capable of measuring forces to within 1% of the FME at a minimum sample rate of 100 times the cyclic frequency used. Displacement shall be measured with linear transducers, or other suitable devices, with a resolution of 0.001 inches for continuously measuring displacement under cyclic loading conditions.

8. Calculations

8.1 The arithmetic mean of the peak loads shall be calculated for each test series. Plot the force-displacement curve for each test, then, using the force-displacement curves, produce an average force-displacement curve to describe the behavior of the tested specimens for each test series.

8.2 Compare the test data of the Proposed Anchors with those of the Code Anchors. Equivalency is defined in Section 3.

8.3 Calculate the strength of the Code Anchor based on concrete cone failure using the code Strength Method.

9. Report

The report shall include the following information for both Code Anchors and Proposed Anchors:

9.1 Date of test and report.

9.2 Name of the test sponsors, testing laboratory and the licensed engineer directing and controlling the test per Section 1.2.

9.3 Detailed description of the test specimen, including the following:

9.3.1 Details of the Proposed Anchor, including:

Material specifications.

Dimensions and tolerances.

Installation equipment. Details of proprietary drilling devices if applicable.

Adhesive specification including special specifications for various installations. (Gel time; setting time; temperature ranges.)

9.3.2 Structural member dimensions. Description of method of proportioning and source of materials, blocks, concrete, mortar and grout, placing, curing and protection to produce the structural member. Report the results of cylinder/prism testing.

9.3.3 The complete manufacturer's installation specifications and instructions as provided and used for production field installation of the Proposed Anchors shall be included in an appendix to the report.

9.3.4 Description of the installation procedure in sufficient detail for assessment of compliance with the manufacturer's written instructions. This description shall include details of any difficulties encountered during installation or any special procedures used for specific installation positions. Relevant information to be provided, includes but is not limited to, the following: quality control procedures; embedment length; edge distance; anchor spacing; drill size; hole depth; tolerances; temperature range; etc...

9.3.5 Certification that installation was in accordance with published specifications and instructions and in accordance with the field verifiable quality control procedures used for actual building construction, based on the required observation per Section 1.2.

9.4 Description of the test.

9.4.1 General narrative of the test program.

9.4.2 Note any modifications made to the test specimen, the test apparatus, or to the testing procedures made during the test.

9.4.3 Detailed description of the mode of failure. This shall include photographs of special conditions observed in specific tests.

9.5 Provide a summary of results including tabulated and graphical comparative representation of peak loads and the average peak load for each test series. Force-displacement curves and the average curve for each test series shall be prepared to establish equivalence of the Proposed Anchor with the Code Anchor. Plot the calculated strength of the Code Anchor determined under 8.3.

9.6 List of observers.

9.7. Photographs with captions and references to appropriate text, describing the test set-up and especially the failure modes.

9.8 Stamp and signature of licensed engineer per Section 1.2.

9.9 Appendix, including the following:

- References
- Raw data
- Anchor design and specifications, and installation instructions per 9.3.2.
- Manufacturer's catalogue listing and recommended use details. This shall be complete and exactly as it will be published.

COMMENTARY
Standard Method of Cyclic Load Test For Anchors in Concrete or Grouted Masonry

C1. Scope

C1.1 Performance analysis of lateral force resisting systems under earthquake loading requires reliable information on expected deformation, strength and ductility of the system. An anchor connected to such a system must develop the strength of the system and have a predictable slip/deformation, preferably insignificant, so that a total lateral deformation of the system may be determined. Information on modes of failure and the reliability of anchors is required by the designer to protect against brittle type failures of the anchors. Anchors commonly have brittle type failure and their strength must exceed the demand on the anchor caused by the ductile elements in the lateral load resisting system.

The current code provides formulae for the calculation of the strength of headed anchors embedded in concrete or masonry. These formulae are based on concrete or masonry failure. These strength values are used directly with other sections of the code for design of lateral load resisting systems. Predicting the performance of types of Proposed Anchors that are substituted for cast-in-place code complying anchors (Code Anchors) and derive tensile resistance from friction or bond is a subject that is not fully understood and is not addressed in the code. An expected strength value is traditionally determined by testing, and a percentage of this expected strength (safety factor) is assigned as an allowable load for these Proposed Anchors. However the behavior of the Proposed Anchors under load, debonding, pull-out, etc., is different from that of the Code Anchor, whether under monotonic or cyclic loading. An arbitrary reduction factor applied to an expected strength value obtained from testing may only be acceptable if it is calibrated against a Code Anchor of equal diameter. It is recommended that the embedded alternative Proposed Anchor be evaluated by tests and shown to be equivalent to the Code Anchor. It is equivalent if it has equal or less displacement versus load, and has equal or greater peak strength when compared with a Code Anchor of equal diameter.

C1.2 No commentary

C2. Referenced Documents   No commentary

C3. Definitions

"Proposed Anchor" is used generally in the text to refer to anchors defined under 3.1, 3.4, 3.7, or 3.10, as opposed to "Code Anchor" defined under 3.2.

C4. Summary of Method

C4.1 No commentary

C4.2 No commentary

C4.3 Testing of the Proposed Anchors side by side with Code Anchors that are installed in the same medium, within a specified time period allows direct comparison of the force-deformation characteristics without concern for the medium's strength variation with time. Tests may be performed at a wide range of medium strengths as requested for approval and strength values may be interpolated between the tested medium strengths.

C4.4 Overhead installation of Proposed Anchors that use flowable materials, such as epoxy or other resins, is a difficult operation that must be adequately controlled. In the past, that operation was left to the field installer's ingenuity to support the Proposed Anchor and at the same time prevent the resin from draining out of the drilled hole. The methods, procedures or supports used for retaining epoxy or grout and for supporting the weight of the embedments during installation shall be fully described and, if shown to be adequate by the testing, shall be included in the manufacturer's specifications for field installation. See C5.2.2.3 sketch at end of this commentary.

C5. Test Specimens

C5.1 The concrete or masonry testing medium must be the same as requested for approval and tested in the manner as required by the code for concrete or masonry for determination of its strength.

C5.1.1 No commentary

C5.1.2 No commentary

C5.1.3 No commentary

C5.2 **Anchor Installation.**

C5.2.1 No commentary

C5.2.2 **Proposed Anchors.**

C5.2.2.1 No commentary

C5.2.2.2 No commentary

C5.2.2.3 Refer to sketch at end of this commentary.

C5.2.2.4 Proposed Anchor installation. Initial torque is known to diminish after the first or second day due to creep in the concrete. The wait time of 48 hours before testing is intended to allow such creep to take place.

C5.2.3 Adjusting the nut to a "finger tight" condition is intended to simulate a long-term condition. For example, to simulate shrinkage in wood attachments.

C6. Test Set-Up No commentary

C7. Procedure

C7.1 No commentary

C7.2 No commentary

C7.3 No commentary

C7.4 No commentary

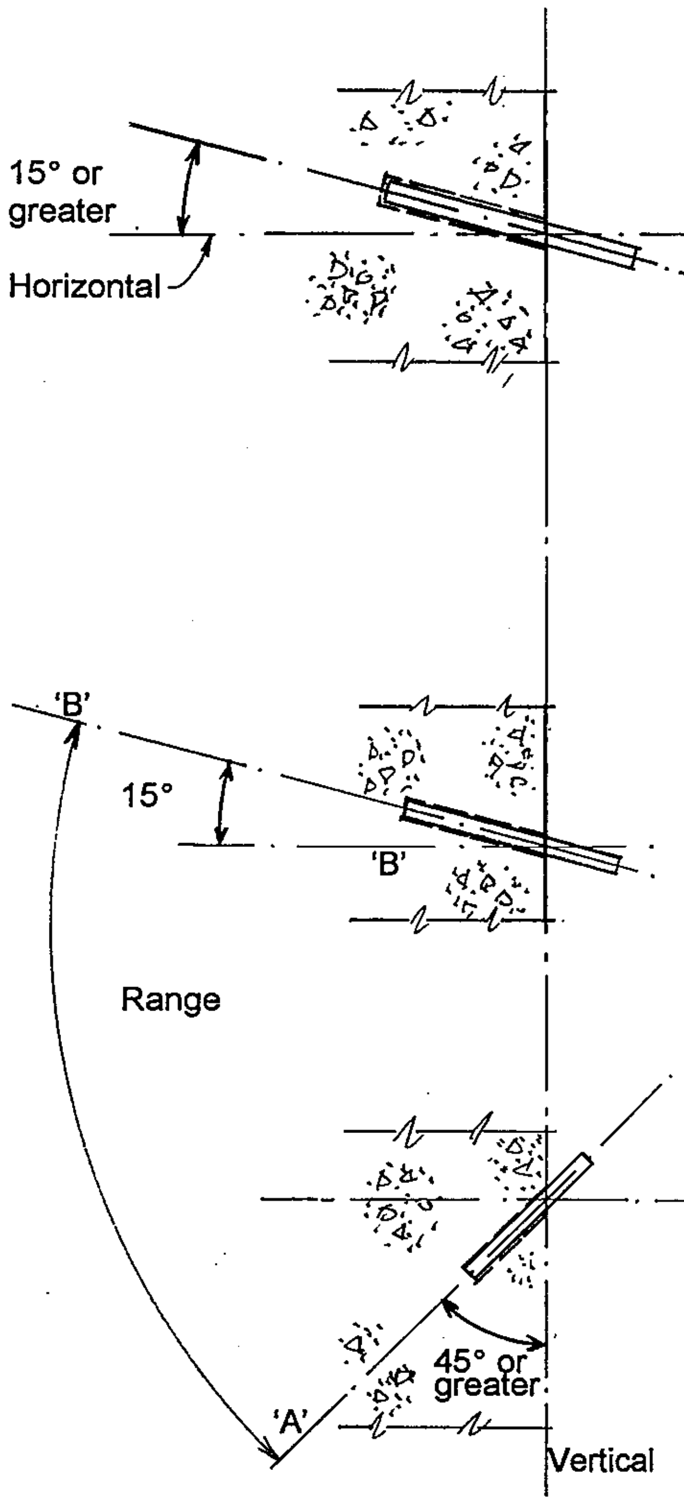
C7.5 FME is not a precise value. FME is best estimated from a preliminary test of an anchor. The minimum of 15 load cycles required prior to reaching 100% of FME is intended to provide enough near-elastic behavioral characteristics to be recorded prior to a predicted non-ductile failure. For anchors that fail in a non-ductile mode the SLS is close to the FME.

C7.6, C7.7, C7.8 The recommended test procedure is force-controlled. Force control is used since deformations up to the FME are expected to be small. Shear forces are applied in fully reversed cycles and tension forces are applied in tensile only loading cycles (without fully reversing load cycles). Displacements are continuously measured.

C8. Calculation No commentary

C9. Report No commentary

C5.2.2.3 Sketch



Proposed Anchors intended for installation at 15° or greater angle to the horzontal shall be installed in the 90° overhead position for testing.

Proposed Anchors intended for installation in the range indicated between 'A' and 'B' (at 45° or more to the vertical and 15° or less to the horizontal) shall be installed in position 'B' for testing.