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Timber structures — Static and cyclic lateral load test methods for shear walls

Structures en bois — Méthodes d'essai de charge latérale statique et cyclique sur murs de contreventement

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 21581 was prepared by Technical Committee ISO/TC 165, *Timber structures*.

Introduction

Evaluation of the structural performance of shear walls intended to resist forces generated during wind and seismic actions is based on static or reversed cyclic load testing in some regulatory jurisdictions. The objective of this International Standard is to provide test methods appropriate for static and cyclic lateral loading as a basis for determining the characteristics of shear walls for use in wind and seismic design. The cyclic displacement schedule in ISO 16670, which was developed in consultation with a group of international experts, was also used in this International Standard.

Supplementary information is given in Annex A to provide the rationale behind the cyclic displacement schedule, recommendations for cases for which a modified schedule would be more appropriate and typical test results obtained on a shear wall specimen by following this International Standard.

Timber structures — Static and cyclic lateral load test methods for shear walls

1 Scope

This International Standard specifies static and cyclic test methods as a basis for the derivation of lateral load resisting parameters which are required in the wind and seismic design of shear walls in timber buildings. This International Standard does not include criteria for parameters which are, at times, stipulated in national standards or building codes. This International Standard can be used to determine those parameters under the following conditions:

a) Method I: the boundary conditions are designed to produce mainly the shear response of the wall and ensure that the full shear capacity of the wall is achieved;

b) Method II: the boundary conditions are designed to produce mainly the rocking (rigid body rotation of the wall) or combined shear-rocking response of the wall reflecting the intended actual construction details of joints connecting the wall to bottom and top boundaries.

This International Standard specifies procedures to ascertain the envelope curves (backbone or skeleton curves) for shear walls subjected to a static or a cyclic displacement schedule.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 554, *Standard atmospheres for conditioning and/or testing — Specifications*

ISO 3131, *Wood — Determination of density for physical and mechanical tests*

3 Symbols and units

F Applied lateral load, in newtons

F_{max} Maximum lateral load, in newtons (for definition, see Figure 3)

F_v Applied vertical load, in newtons

H Height of wall specimen, in millimetres

K Displacement modulus, in newtons per millimetre

l Horizontal displacement of wall, in millimetres

l_u Ultimate horizontal displacement of wall, in millimetres (for definition, see Figure 3)

4 Test specimens

4.1 Conditioning

The specimens shall be conditioned at the controlled environment of (20 ± 2) °C and (65 ± 5) % relative humidity in accordance with ISO 554 as far as possible. The test laboratory shall normally be maintained at the controlled environment, but when other conditions apply, they shall be reported.

The density of the wood members in the wall specimen shall be determined in accordance with ISO 3131.

4.2 Form and dimension

The dimensions (e.g. height and length), configuration (e.g. openings) and fabrication details (e.g. elapsed time between the fabrication and test, tolerances, and conditioning details before and after fabrication) shall be representative of the intended end use.

Where panels are used, the wall specimen shall consist of a single or multiple panels of the representative dimensions.

Some wall configurations can have joints between wall units. Those joints should be considered for inclusion in test specimens.

4.3 Sampling

Sampling shall provide for selection of representative test material on an objective and unbiased basis, covering an appropriate range of physical and mechanical properties.

The number of replicates should be selected to achieve the specific objectives and desired reliability.

5 Apparatus

5.1 General

The test apparatus (Figure 1) shall be capable of producing the boundary conditions that are intended in Methods I and II.

NOTE 1 For further information, see A.2.

The testing machine shall be capable of applying and continuously recording load and displacement to an accuracy of ±1 % of the estimates of F_{max} and l_u or better.

Where the lateral loads, F, are applied along with the vertical loads, F_V, the test apparatus shall be capable of controlling the vertical loads and the lateral loads separately.

Where the lateral loads are applied along with the vertical loads, it is recommended that the frictional forces be taken into consideration. Vertical load should not produce horizontal component.

In Method I, the full shear capacity of the wall specimen is achieved through application of sufficient vertical loads and adequate vertical restraints (e.g. hold-down connectors) or tie-down rods (at both ends of the wall specimen in the cyclic test).

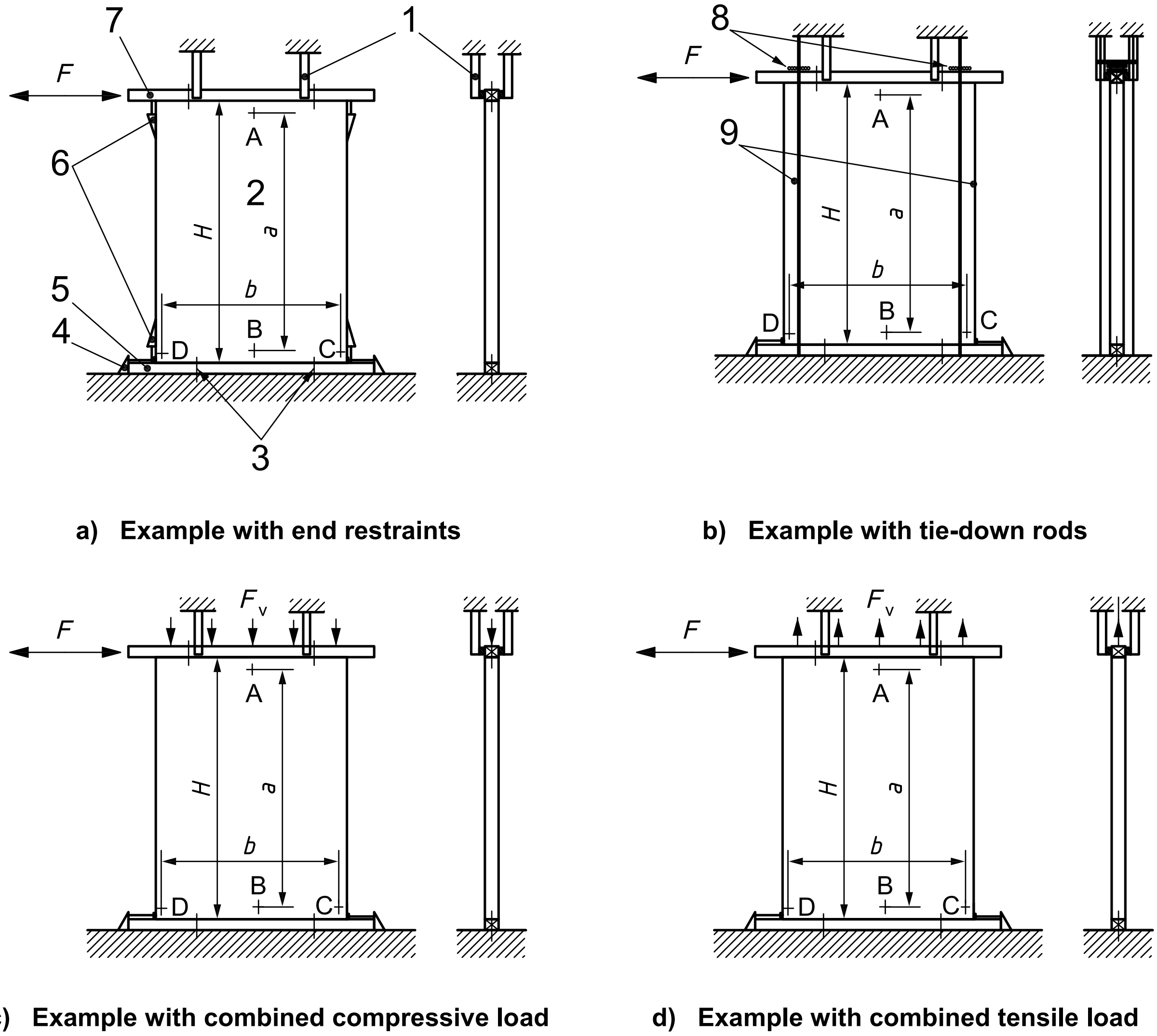
Where hold-down connectors are used, they shall be attached in such a way that they are effective primarily in resisting the up-lift forces, and the additional resistance that the wall gains due to hold-down connectors shall be determined.

Method I is intended to result in shear failure in the wall specimen. It is therefore recommended that, if so desired, the end members be designed in such a way as to avoid crushing and buckling failures. It is also recommended that hold-down connectors be used at the top of the wall if separation of horizontal and vertical members is not desired. Where tie-down rods are used, the frictional forces should be taken into account.

In Method II, the wall specimen shall be tested with representative boundary conditions (e.g. anchorage, hold-down connector details) and the vertical (compressive or tensile) loads that are expected in actual construction.

NOTE 2 Method II can result in failure in the wall or in anchorage or vertical restraints (hold-down connectors).

Measuring point A should be as close to the top of the wall as practicable.



Key

1	lateral restraint	a	distance between points A and B
2	wall specimen	b	distance between points C and D
3	anchor bolt	F	lateral load
4	horizontal restraint	F_v	applied vertical load
5	base beam	H	height of wall
6	vertical restraint		
7	loading beam		
8	roller		
9	tie-down rod		

Figure 1 — Examples of test apparatus

5.2 Base of test frame and loading beam

The base of the test frame shall provide a level foundation for the test specimen and shall be relatively stiff, such that its deflections are negligible. A rigid datum (independent of the test frame) shall be provided for the measurement of the deformation of the wall specimen.

The loading beam, if applicable, shall be firmly attached to the top of the wall specimen to ensure uniform distribution of lateral load. The actuator that is attached to the loading beam to apply the lateral load shall be installed in such a way that does not restrain up-lift. In all cases, the stiffness and the mass of the loading beam shall be determined. The cross-sectional dimensions and position of the beam shall allow the free movement of the panels during the test, unless otherwise specified by the test objectives.

A rigid or flexible loading beam may be used depending on the intended end use. In Method I, a rigid loading beam shall be used. In Method II, stiffness of loading beam may be chosen according to the intended actual construction.

5.3 Mounting of wall specimen

The wall specimen shall be connected to the base of the test frame with anchor bolts or other connectors according to the actual end use in structures.

In Method I, anchor bolts and vertical restraints (hold-down connectors) shall be designed in such a way as to allow the wall to fail in shear.

Lateral restraints shall be provided through the loading beam such that the top of the wall specimen deflects only in the plane of the wall.

6 Test procedure

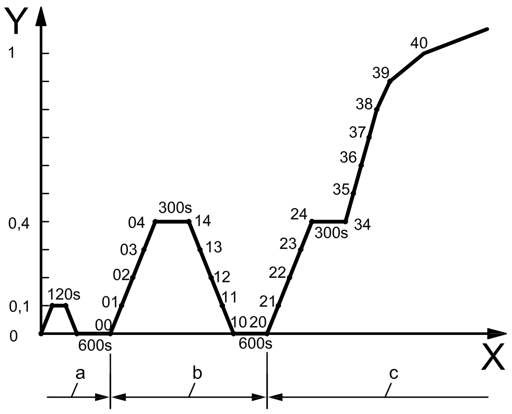
6.1 Static (monotonic) test

The lateral load, F, shall be applied as shown in Figure 1. The load shall be applied at a constant rate of movement related to the displacement at gauge A. For loading and unloading up to 0,4 F_{max} (estimated), the rate of loading shall be $(0{,}000\,8H \pm 0{,}000\,2H)$ mm per min (H: height of wall) . For loading above 0,4 F_{max} (estimated), the rate of loading shall be selected to achieve ultimate displacement between 5 min and 30 min. The procedure for the application of the lateral load is shown in Figure 2.

The displacements of the wall specimen shall be monitored at points A, B, C and D (see Figure 1). The deformations, l_{rel}, shall be taken as the displacement at A minus the displacement at B. The displacements at C and D shall be reported separately.

The mean value (where applicable) of the ultimate displacement l_u of the static tests will be determined by following the definition of l_u in Figure 3.

NOTE Static (monotonic) test procedure is adopted from EN 594.



Key

X time, in seconds

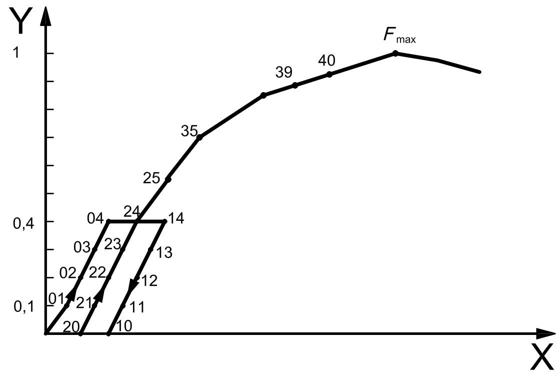
Y $\frac{F}{F_{max,est}}$

a Stabilizing load cycle.

b Stiffness load cycle.

c Strength test.

a) **Lateral load versus time**



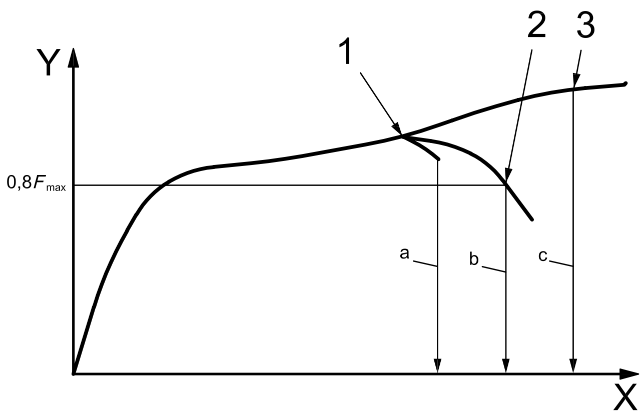
Key

X deformation, in millimetres

Y $\frac{F}{F_{max,est}}$

b) **Typical lateral load versus deformation**

Figure 2 — Static tests procedure



X displacement, l

Y load, F

1 F_{max} (case a, case b)

2 displacement at failure

3 F_{max} (case c)

a l_u (case a), displacement at failure.

b l_u (case b), displacement for 0,8 F_{max}.

c l_u (case c), displacement = H/15.

Definition of ultimate displacement: l_u corresponds to displacement at failure (case a), displacement at 0,8 F_{max} in the descending portion of the load-displacement curve (case b), or displacement reaching to H/15 (case c), whichever occurs first in the test.

Figure 3 — Ultimate displacement

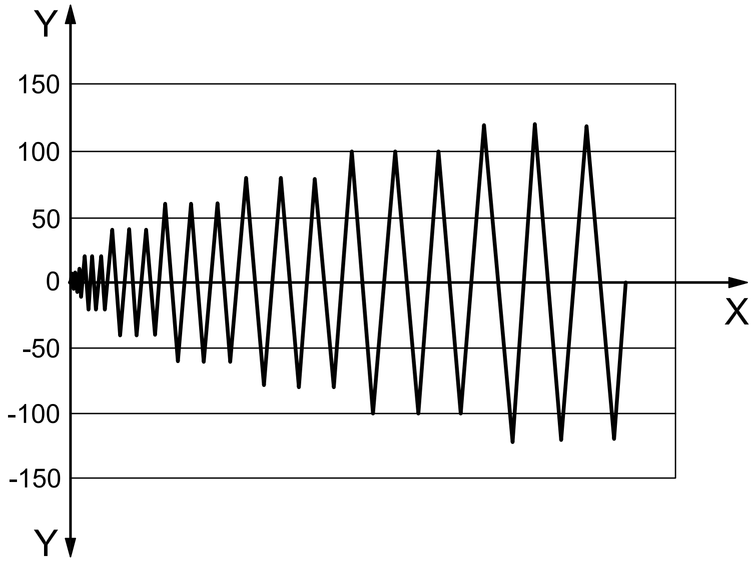
6.2 Cyclic test schedule

The cyclic displacement test schedule shall produce

a) data that sufficiently describe the elastic and inelastic cyclic properties of the wall specimen, and

b) demands representative of those imposed on the walls by earthquakes.

The cyclic displacement schedule given in Figure 4 shall be followed with a rate of displacement to achieve ultimate displacement between 1 min and 30 min. The amplitudes of the reversed cycles are a function of the mean value (where applicable) of the ultimate displacement, l_u, obtained in the static (monotonic) test. Table 1 shows the amplitudes as a percentage of the ultimate displacement.



Key

X time, in seconds

Y displacement, in percent l_u

NOTE An alternative cyclic displacement schedule (either velocity- or frequency-based) that satisfies the principles given above can also be employed to achieve the test objectives. Methods A and C in ASTM E2126 satisfy the principles (ISO protocol is included in Method B of ASTM E2126).

Figure 4 — Cyclic displacement schedule

Table 1 — Amplitudes of the reversed cycles

Step	No. of cycles	Amplitude
1	1	1,25 % of l_u
2	1	2,5 % of l_u
3	1	5 % of l_u
4	1	7,5 % of l_u
5	1	10 % of l_u
6	3	20 % of l_u
7	3	40 % of l_u
8	3	60 % of l_u
9	3	80 % of l_u
10	3	100 % of l_u
11	3	Increments of 20 % of l_u
NOTE Some of the initial steps (1,25 % l_u to 10 % l_u) can be omitted or repeated (or new steps), depending on the stiffness of the walls or accuracy of the measurement system, as long as the principles given in 6.2 are satisfied. A.4 identifies cases where modification of the standard cyclic displacement schedule can be warranted.		

7 Test results

7.1 Hysteresis data

The complete hysteretical response data (load-displacement) shall be plotted and stored for each test wall. In organizing raw data (whether tabulated on paper or stored in a computer file),

— time,

— input displacement,

— measured load, and

— measured displacement

shall be included.

7.2 Envelope curves

The first, second and third envelope curves for the cyclic tests shall be established by connecting the points of maximum load in the hysteresis plot in each displacement level in the first, second and third reversed cycles, respectively. The maximum load values and their associated displacements obtained in the first five single reversed cycles shall be taken to be the same for all envelope curves.

NOTE For an example, see Figure A.1.

7.3 Properties of wall specimen

The maximum loads and ultimate displacements (both defined in Figure 3 and in both directions taken from the three envelope curves) shall be reported in tabular form in case of reversed cyclic test.

NOTE For an example, see Table A.1.

8 Test report

The test report shall include:

a) specification of

   1) the global source (where appropriate), species, grades of wooden members and sheathing and other materials,

   2) the dimensions and grade of steel and fasteners, and

   3) the sampling and conditioning methods;

b) a description of the fabrication details (e.g. elapsed time between fabrication and test);

c) a description of the wall specimen (e.g. dimensions and configuration of the wall specimen, and application of sheathing panels) and the loading configuration;

d) a test matrix showing the number of replicates for each test group;

e) a description of the test apparatus and diagram of test set-up with location of measuring devices and any restraints;

f) a description of the cyclic displacement schedule, including the displacement rate;

g) a statement of any deviation from this International Standard;

h) report the sampling speed for data collection;

i) a plot of the hysteresis data (load-displacement data) and tabulated envelope curves, maximum loads, ultimate displacement, moisture content of the wood at the time of fabrication, and test and failure modes.

Annex A
(informative)

Additional information

A.1 Application of vertical loads

This International Standard allows application of compressive or tensile vertical loads during the lateral loading test. Compressive vertical loads act against overturning moment due to lateral load, but cause additional compressive demand, which may cause buckling or compression perpendicular to grain failure, particularly at the end of the wall specimen. Information about application of tensile vertical loads during the lateral load test is limited.

Application of vertical load may follow the following scheme.

a) Vertical compressive load applied should be applied first, then constant and static or cyclic lateral loads (seismic or wind).

b) Vertical tensile load applied should be applied first, then constant and static lateral load (wind).

c) Vertical tensile load and static lateral load applied simultaneously. The proportion of vertical load to lateral load should be determined to simulate actual conditions (wind).

A.2 Boundary conditions

Boundary conditions, such as the tightening of anchor bolts and the stiffness of the loading beam can influence the results depending on the aspect ratio, wall configuration and the continuation of loading beam over the discontinuity of the wall specimen.

— In Method I these conditions should be selected in such a way as to achieve full shear capacity of wall specimen.

— In Method II boundary conditions should be selected to simulate actual conditions.

A guideline national standard or european standard can be useful to define these conditions (e.g. EN 594, ASTM E72, ASTM E564, ASTM E2126 and JIS A1414-2).

A.3 Rationale behind the cyclic test schedule

a) This International Standard also provides a cyclic test method to ascertain the envelope (backbone or skeleton) curves for test walls subjected to a cyclic displacement schedule with a displacement pattern that results in similar failure mode and energy dissipation as would occur under seismic action.

   The cyclic displacement schedule includes the application of reversed cycles in terms of percentage of the wall's ultimate displacement from static test, a property which can be easily determined and which is defined with reasonable agreement throughout the world.

   This method does not depend on a yield displacement. It is difficult to reach an agreement on its definition because of differences in national standards. However, one can use the static (monotonic) and cyclic test results to determine the yield displacement according to any given definition.

b) This method generates suitable data in the elastic and inelastic ranges. In the elastic range, only one cycle is applied for each of the displacement levels (1,25 %, 2,5 %, 5 %, 7,5 % and 10 % of ultimate displacement). In the inelastic range, this method generates three envelope curves which are evenly distributed along the displacement axis. These envelope curves may be used to determine impairment of strength, ductility and yield displacement, according to the definitions adopted in different jurisdictions.

c) It is desirable to perform the reversed cyclic tests within a few minutes because earthquakes do not generally last more than 1 min. This International Standard allows the cyclic test to be performed between 1 min and 30 min. A lower bound of 1 min was selected with the intention of avoiding dynamic effects to the test specimen. An upper bound of 30 min was selected as the lowest rate to accommodate the use of test equipment which has limitation in applying relatively high rates of displacements. This International Standard allows for the use of velocity- or frequency-based test protocols.

A.4 Modification of ISO displacement schedule

The ISO displacement schedule should be modified in cases where:

a) the behaviour of the wall is significantly different in two opposite directions. In this case, monotonic tests should be performed in both directions. The ultimate displacement in the cyclic displacement schedule should then be determined for each direction based on their respective ultimate displacement obtained in static (monotonic) tests;

b) the wall exhibits inelastic behaviour within five initial steps. In this case,

   1) new single steps may be added to ensure a minimum of three steps for obtaining sufficient data within the elastic range; and

   2) initial steps beyond the elastic range should be repeated three times to generate three envelope curves;

c) the amplitudes of the first and second steps are too small (e.g. glued applications) to be accurately applied. In this case, the first and second steps may be omitted;

d) decreasing cycles are necessary (e.g. to generate suitable data for calibration of hysteresis models). In this case, the application of single decreasing cycles before increasing to the next displacement cycle may be added to the displacement schedule;

e) specific earthquake effects are studied. For instance, to study near-fault, site-specific earthquake effects or cumulative damage due to multiple earthquakes, other cyclic displacement schedules can be more appropriate [e.g. near-fault cyclic schedule developed for Los Angeles, California, by the Consortium of Universities for Research on Earthquake Engineering (CUREE)].

A.5 Comparison of test results with different test procedures

An earlier version of the ISO cyclic test schedule was applied to wood shear walls and the results were compared with those obtained using the draft CEN and draft ASTM (which at that time only included the sequential displacement method or “SPD”) schedules, and the calculated wall displacement response from tests conducted using six earthquake records as the input displacement (see Reference [10]). Among other results, it was observed that the energy demand of the draft ISO and CEN schedules was in the high end of the range of values obtained from tests with six earthquakes, while the energy demand of the SPD schedule was about two times that of draft ISO and CEN schedules. With the SPD schedule, a high number of nail fatigue failures were observed. This type of failure has rarely been observed in damaged wood structures after earthquakes. An appropriate test procedure is one that includes a failure mode in the specimen which is similar to that observed under earthquake loading.

ISO 16670 was published in 2003. Background information on ISO 16670 is reported in Reference [11]. Its cyclic displacement schedule is included in ASTM E2126 for cyclic (reversed) load testing for shear resistance of walls for buildings. ASTM E2126 includes two other cyclic displacement schedules, one based on the sequential-phased displacement (SPD) procedure and another based on the CUREE basic loading schedule in Reference [12]. This is a positive step towards acceptance of results. Reference [9] reported that test results on nailed shear walls with the ISO cyclic schedule were between those obtained with the CUREE basic cyclic displacement schedule and the SPD schedule; the latter resulted in relatively low load-carrying capacities due to excessive nail fatigue failures. These findings are consistent with those reported in this clause.

A.6 Properties of wall specimen

Properties, such as stiffness, yield displacement, ductility and impairment of strength, can be determined from the envelope curves according to the definitions adopted in different jurisdictions.

Stiffness may be calculated by

$$K = \frac{0{,}3\,F_{\text{max}}}{l_{40\,\%\,F_{\text{max}}} - l_{10\,\%\,F_{\text{max}}}}$$

for the static (monotonic) and first, second and third envelope curves of the cyclic test specimens. $l_{40\,\%\,F_{\text{max}}}$ and $l_{10\,\%\,F_{\text{max}}}$ are the displacement values obtained at 40 % and 10 % of the maximum load, F_{max}, respectively, for the respective envelope curve.

In the future, there could be a need to determine some additional properties, such as energy dissipation. For that purpose, it is recommended that data be stored preferably in digital form for complete description of the hysteresis loops, as described in 7.1.

Horizontal relative displacement, l_{rel}, gross shear deformation angle, γ_{rel}, rotation angle due to up-lift and embedment at the end of the wall, γ_{rot}, and true shear deformation angle, γ_{true}, of wall specimen can be calculated as follows:

$$l_{\text{rel}} = l_{\text{A}} - l_{\text{B}}$$

$$\gamma_{\text{rel}} = \frac{l_{\text{rel}}}{a}$$

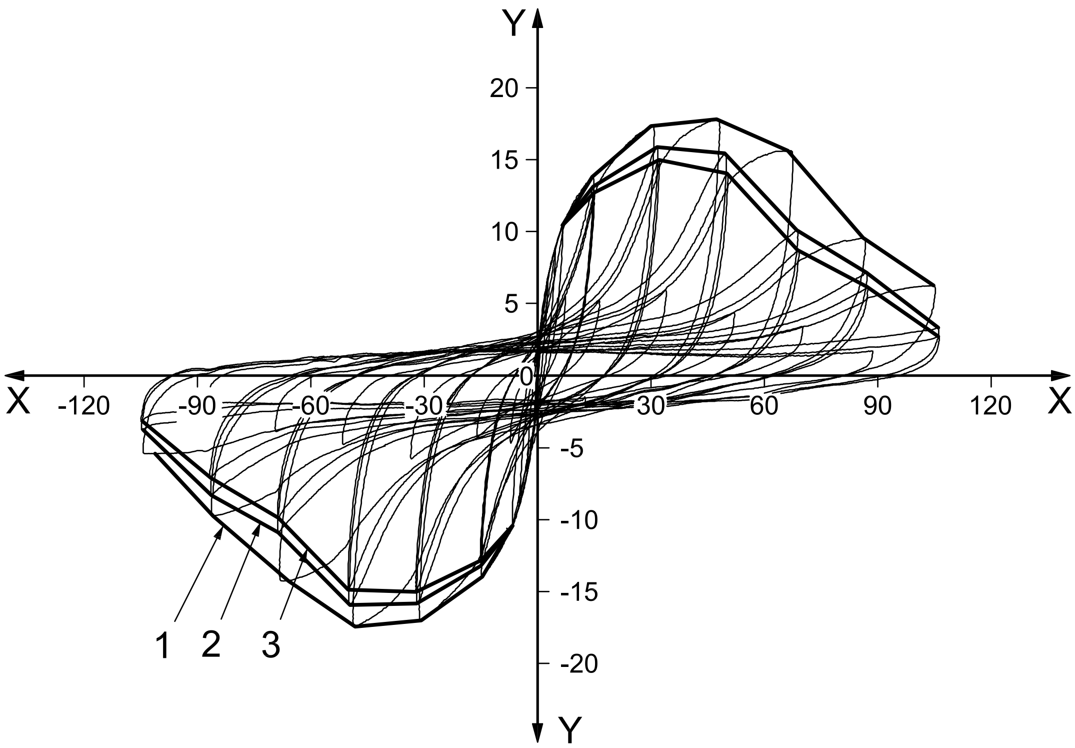
$$\gamma_{\text{rot}} = \frac{l_{\text{D}} - l_{\text{C}}}{b}$$

$$\gamma_{\text{true}} = \gamma_{\text{rel}} - \gamma_{\text{rot}}$$

where

l_{A}, l_{B}, l_{C} and l_{D}	are the displacements at points A, B, C and D (see Figure 1);
a and b	are the distances between points A and B, and points C and D.

A.7 Example of load-displacement curve and tabular form



Key

1 first envelope curve

2 second envelope curve

3 third envelope curve

X load, F, expressed in kilonewtons per metre

Y displacement, l, expressed in millimetres

Figure A.1 — Envelope curves traced from hysteresis data

Table A.1 — Tabulated values of points defining the envelope curves

First envelope curve				Second envelope curve				Third envelope curve			
Positive		Negative		Positive		Negative		Positive		Negative	
mm	kN/m	mm	kN/m	mm	kN/m	mm	kN/m	mm	kN/m	mm	kN/m
0,3	1,53	–0,2	–1,36	0,3	1,53	–0,2	–1,36	0,3	1,53	–0,2	–1,36
0,9	3,65	–0,9	–3,56	0,9	3,65	–0,9	–3,56	0,9	3,65	–0,9	–3,56
2,7	6,80	–2,7	–6,74	2,7	6,80	–2,7	–6,74	2,7	6,80	–2,7	–6,74
4,7	8,86	–4,7	–8,92	4,7	8,86	–4,7	–8,92	4,7	8,86	–4,7	–8,92
6,6	10,43	–6,6	–10,43	6,6	10,43	–6,6	–10,43	6,6	10,43	–6,6	–10,43
14,5	13,81	–14,6	–13,98	14,8	13,13	–15,1	–13,24	15,1	12,72	–14,9	–12,84
30,0	17,34	–30,8	–17,02	31,7	15,88	–32,0	–15,84	32,1	14,99	–32,1	–15,03
47,4	17,81	–48,3	–17,46	49,5	15,45	–49,6	–15,96	50,1	14,05	–50,1	–14,89
66,2	15,62	–65,9	–14,27	68,6	10,10	–68,6	–10,90	68,8	8,72	–68,6	–9,89
86,1	9,56	–85,8	–9,76	87,0	7,16	–86,3	–8,33	87,2	6,17	–86,4	–7,11
104,8	6,26	–101,2	–5,43	106,0	3,33	–104,4	–3,77	106,0	2,73	–104,7	–3,16

Table A.2 — Type of curve

Type of curve		Maximum load kN/m	Ultimate displacement mm
First envelope curve	Positive	17,81	70,7
	Negative	–17,46	–67,3
Second envelope curve	Positive	15,88	59,3
	Negative	–15,96	–61,6
Third envelope curve	Positive	14,99	57,3
	Negative	–15,03	–60,7

NOTE In the example, the ultimate displacement is defined as the displacement at 80 % of the maximum load in the descending portion of the load-displacement envelope curve.

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