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A wall bracing test and evaluation procedure

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Revision note

This is an adaptation of P21 (1988) and TR10 (1991) to incorporate current best practice, remove ambiguities and prepare for publication and citation in NZS 3604. NZS 3604 is currently under revision and due for publication in late 2010.

Abstract

The P21 test method has been in existence almost unchanged since 1979, with a supplement published in 1991 to reflect the change from working stress design to limit states design. It is cited in NZS 3604 *Timber framed buildings* and is still in regular day-to-day use to determine wind and earthquake ratings of bracing elements generally within the scope of NZS 3604. With the imminent publication of an updated revision to NZS 3604, it was decided to update the P21 method to incorporate current best practice, remove ambiguities, align with the new loadings standard AS/NZS 1170 and prepare for citation in NZS 3604. There is a new section covering the application of brace ratings, including its use in specifically designed buildings. The resulting document is the culmination of input from the members of the NZS 3604 review bracing subcommittee and researchers at BRANZ.

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1. SCOPE AND USE

Bracing ratings evaluated in accordance with this procedure are intended to be used for the design of buildings coming within the scope and framework of NZS 3604 *Timber framed buildings*.

Therefore, the methodology is focused on the determination of bracing ratings of timber-framed elements whose resistance is basically dependent on the behaviour of steel fasteners, installed into the timber frame, under lateral (shear) loading. The procedure is not intended to be used for evaluating the performance of concrete or masonry walls, steel-framed walls, post and beam, plank construction or panellised construction, unless the critical components of the wall are laterally loaded steel fasteners installed in timber.

(Note: The scope includes, but is not limited to, elements with sheet linings or claddings (for example, gypsum plasterboard, plywood, fibre-cement, OSB or MDF), strip cladding or lining (for example, weatherboards, board and batten, match lining), steel or timber diagonal braces fixed to the frame. Refer to Section 14 for application of this test procedure, which discusses these issues.)

The bracing ratings derived are only applicable to the construction tested.

2. TEST AND EVALUATION OBJECTIVES

The test is intended to evaluate the performance of wall bracing elements and their fixings when subjected to in-plane racking load. Such performance includes consideration of:

- a) adequate strength to withstand the maximum likely wind and earthquake loads
- b) adequate stiffness to avoid excessive deflections
- c) adequate elastic recovery after loading to prevent unacceptable permanent deflection
- d) resistance to repeated loading and demonstration of ductility and reserve of strength so that earthquake energy can be adequately dissipated.

3. DEFINITIONS

Bracing rating (earthquake)	The bracing rating derived from analysis of forces resisted by three test bracing walls as defined in Section 12.1, expressed in BU.
Bracing rating (wind)	The bracing rating derived from analysis of forces resisted by three test bracing walls as defined in Section 12.2, expressed in BU.
Bracing unit (BU)	<p>A unit of force used to value the overall bracing performance of a panel tested to the P21 test method. By definition, 1 kN = 20 bracing units.</p> <p>It is also used in NZS 3604 to express the magnitude of wind and earthquake bracing demand.</p>
Cyclic displacement set	A set of three displacement cycles to a designated displacement, first in a positive direction and then in a negative direction.
Ductility	A measure of the inelastic behaviour of the test specimen under earthquake action.
Notes	Notes within this document are informative only and are not a mandatory part of the verification procedure. <i>(They are in italic text.)</i>
Sheet lining	Wall lining material formed from large (typically 2.4 m x 1.2 m) sheets, typically fixed to the frame with discrete fixings (screws or nails).
Supplementary uplift restraints	Devices attached to each end of the specimen to provide a level of uplift restraint that can reasonably be anticipated in service.
Timber-framed wall	A wall built of spaced timber stick members and lined on one or both faces. Lateral resistance of the wall is achieved through the in-plane resistance of sheet lining or cladding fixed to the face of the framing elements or by bracing members fixed to the frame.

4. NOTATION

(in order of appearance in text)

H	Overall height of test specimen (mm).
y	Test displacement of the top of the wall relative to the bottom, within the range ± 15 mm to ± 36 mm.
C	Residual displacement of the specimen after the first 8 mm cycles (mm), i.e. the average displacement recorded when the first cycle loads return to zero.
K1	Displacement recovery factor, defined in Section 12.
+/-P_y	Force recorded during the first displacement cycle to +/-y mm (kN), defined in Section 12.
+/-R_y	Force recorded during the fourth displacement cycle to +/-y mm (kN), defined in Section 12.
P	Maximum measured force (kN).
d	Displacement parameter used to assess the 'ductility' of the specimen, defined in Section 12 (mm).
μ	Ductility of the specimen, defined in Section 12.
K4	Ductility factor, accounting for inelastic behaviour of the system, defined in Section 12.1.
EQ	Calculation parameter being the ultimate earthquake rating of a single wall at a target displacement (kN).
BR_{EQ}	Single wall indicative earthquake rating (BU), defined in Section 12.1.
BR_w	Single wall indicative wind rating (BU), defined in Section 12.2.
K2	Systems factor, accounting for the redundancy present in the structure at serviceability limit state (SLS) load levels, defined in Section 12.

5. PRINCIPLE

The bracing rating of a specified bracing wall system is determined by experimentally subjecting three nominally identical full-scale specimens to an incremental series of cyclic lateral in-plane displacement sets and measuring the force that the wall resists within a defined displacement range. The test arrangement is illustrated in Figure 1.

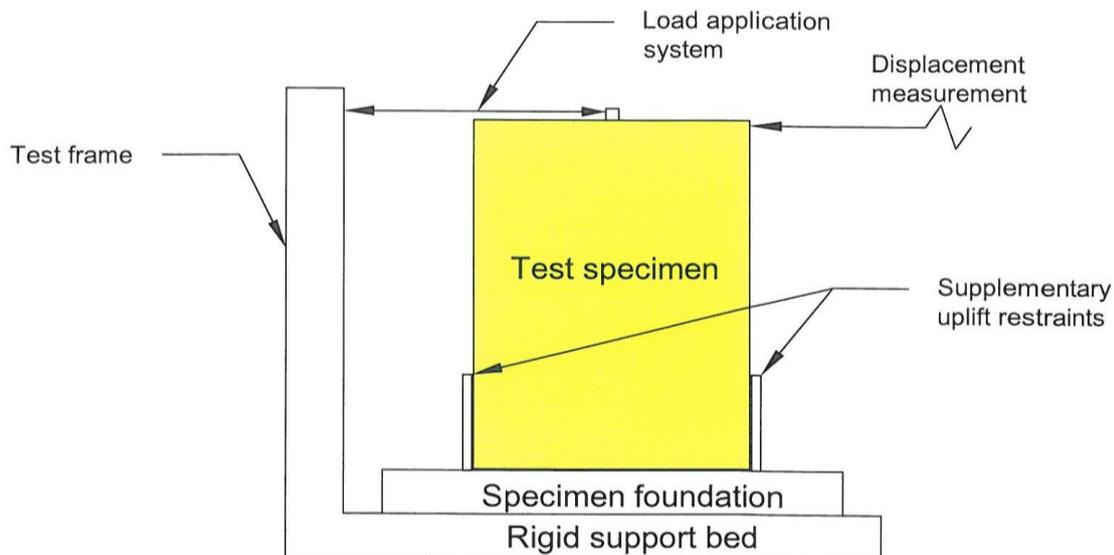


Figure 1. Test arrangement

This test procedure derives a bracing rating for both wind and earthquake as the lower of the rating derived from serviceability and ultimate limit state criteria.

The serviceability criterion is a function of the average force resisted by the wall at a nominated top plate displacement. It is deemed that damage, commensurate with serviceability level loading, is satisfactory up to, but not exceeding, this displacement. The ultimate limit state resistance to earthquake action is the maximum force resisted during the fourth cycle of a displacement series within the defined deformation range, factored to account for inelastic behaviour. The ultimate limit state resistance to wind action is the maximum force resisted within the defined deformation range.

The approach has been taken to evaluate wall bracing performance within a defined deformation range to allow racking resistances of different wall types and lengths within a building to be added.

Vertical loads and vertical restraint from the surrounding structure can improve the racking stiffness of a section of wall by reducing its rotation about its base. The amount of improvement for a given degree of vertical loading is related to the stiffness and strength of the wall-to-floor attachments in relation to the shear stiffness of the complete wall section. Provision is made in the test method for testing the wall under vertical end restraint representative of the restraint provided by the adjacent construction in a building.

6. TEST APPARATUS AND SET-UP

The wall must be tested in the vertical position to allow unrestricted observation of the wall while the test is in progress, to permit dead loading of the top edge of the wall when required, to allow for the effects of the dead weight of the wall itself and to minimise unwanted frictional effects.

The following apparatus is required to conduct this test:

6.1 Test frame

- a) A test frame shall be of sufficient size that full-scale specimens with a minimum height of 2.4 m and length equal to that dictated by the test specification, together with ancillary supports (for example, foundation beams etc.), can be installed.
- b) The frame shall be built in a manner such that it does not provide artificial restraint during the load cycles and does not restrain the specimen in any way such that higher bracing values may result.
- c) The frame shall include a rigid support bed that allows the wall to be fixed at the base according to its specification and using supplementary uplift restraints (see Section 10.4). The support bed shall be sufficiently rigid that the attachment points to any uplift restraints do not displace any more than 0.1 mm at any stage during the test.
- d) The frame shall have provision for a lateral restraint mechanism to prevent significant out-of-plane distortion along the top of the specimen. The mechanism used to control out-of-plane distortion of the specimen as it is laterally displaced should be located at each end of the top of the specimen. The mechanism shall not restrain the specimen from in-plane movement but shall be sufficiently rigid that it will not permit the specimen to distort more than 5 mm out of plane over the expected load range.

6.2 Load application system

- e) An actuator of sufficient capacity and travel to fail the specimen under the intended action at the prescribed loading rate shall be controlled (manually or automatically) so as to follow the nominated test sequences at the prescribed loading rate.
- f) The load application system must only impose horizontal in-plane load to the specimen top plate and not restrict any other specimen deformation.

(Note: It is recommended that the loading system consist of a hydraulic actuator, load cell(s) and a connector having a universal joint at the actuator end and a horizontal pin at the specimen end. Thus, the wall may lift (rock) without restraint and have limited lateral movement without imposing shear forces across the load cell.)

6.3 Measurement system

- g) The applied load shall be monitored by a load cell calibrated to Class 1 in accordance with International Standard ISO 7500-1 over the load range 0.5 to 1.1 times the peak load resisted by the test specimen.

(Note: It is recommended that the applied load be monitored by two independent systems, such as two load cells in series. Checks should be made to ensure the forces registered by the independent systems are within 0.3 kN at all stages of the test.)

- h) Measurements of in-plane deflection shall be made at the top of the specimen. The method of measurement shall be such that it will not be affected by either vertical movement at the point of measurement or by test rig deflections under load. The displacement measurements shall be accurate to within 0.5 mm at all stages of the test.

(Note: Horizontal slip of the bottom of the wall relative to the foundation may be monitored during the test. This information may be useful for product development, to isolate slip deflection from panel deflection.)

6.4 Recording system

- i) Force and deflection measurements shall be recorded so that a complete plot of load versus deformation (as prescribed in Section 11.2) may be made. Deflections at zero load and loads at zero deflection shall also be recorded.

(Note: Automatic direct plotting of load versus deflection is desirable.)

7. SAMPLING

A minimum of three specimens, built to the same specification, shall be tested.

Timber framing members shall be of a grade and shall have dimensions that are representative of that to which the rating is to be applied. Sheathing materials and fasteners supplied for testing shall be representative of those being manufactured.

8. TEST SPECIMENS

The specimens shall as far as possible be representative of the minimum specified construction with respect to dimensions, material and fasteners. In particular, the specimen length shall be the length for which the performance rating is sought.

8.1 Bracing system specification

The system proprietor shall provide a detailed specification for the bracing system to be tested. This shall include the following information:

- a) The specification for the frame construction, which should normally be in accordance with NZS 3604. Unless otherwise specified as part of the bracing system, the following frame construction details shall be used to ensure consistent results between laboratories. Timber framing shall be kiln dried radiata pine, graded SG8 at a maximum moisture content of 18% (verification by meter is acceptable). Framing members shall be the maximum spacing and minimum cross-section that may be used in actual construction for the scope of application. The plates shall be nailed to the studs with two 90 x 3.15 power-driven nails. No dwangs (nogs) shall be used unless required by the system specification.

- b) The sheathing parameters, including the sheet thickness, density and orientation, the face(s) of the frame onto which the sheathing is to be installed.
- c) The fastener type (including base material, head and shank diameters, shank length and surface finish), the fastener spacing around the edges of the specimen and within the body of the specimen and the fastener locations relative to the corners of the sheathing.

(Note: Lining should not be glued to the framing unless the adhesive has been assessed as having a durability in this application of greater than 50 years.)

- d) The specification of any jointing system that provides continuity between sheets. Where appropriate, this specification shall include the method of stopping, the stopping compound(s) to be used, the application method and the joint reinforcement (if any).
- e) Specification of the fixing method to be used for installation to the floor of a building. Where this is different (or additional) to the provisions of NZS 3604, the details provided in the specification shall cover type and spacing of fasteners, plus any specific installation requirements.

(Note: A bracing panel bolted to a concrete floor slab may behave in a different manner to the same panel nailed to a timber floor.)

These details (a to e) are to be included in the test report to the extent that the bracing wall to be tested can be clearly identified and replicated.

8.2 Specimen construction

Each specimen shall be built in accordance with the system specification and the manufacturer's instructions. A standard of workmanship equivalent to good trade practice should be achieved.

The specimen length, measured between the outside faces of the end studs, shall be equal to the sheet size/length, and this becomes the rated element length.

(Note: This recognises that almost all practical bracing elements will end at a trimmer stud (door or window) or at a corner stud.)

Where the specimen length is equal to or less than half the manufactured width of the sheet, the three test specimens shall be constructed with the following edge arrangements (in the orientation as listed with respect to the position of the actuator):

- Manufactured edge/cut edge.
- Cut edge/cut edge.
- Cut edge/manufactured edge.

Where the specimen length includes a sheet greater than half the manufactured width, the three test specimens shall be constructed with the following edge arrangements:

- Cut edge adjacent to the actuator.
- Cut edge at the opposite end.
- Cut edge in the position giving the lowest result from the previous two cases.

Fixings shall be installed to a depth/tightness consistent with good trade practice. For example, plasterboard fasteners must be sufficiently embedded below the sheet surface to allow stopping to take place. Holding down bolts/screws shall be tightened to an extent consistent with good trade practice.

Dimensional tolerances shall be consistent with those resulting from good trade practice. (This is satisfied as being ± 5 mm for any nominated dimension except for ± 2 mm for fastener edge distance.)

9. CONDITIONING

The specimens shall be constructed and tested in a condition representative of the anticipated construction and in-service situation, for example, frames shall be allowed to dry to the anticipated in-service moisture content (18% maximum) before testing. Temperature and humidity conditions during construction and test shall be recorded by the testing agency but need not be reported in detail.

(Note: Materials may be conditioned to 20°C and 65% relative humidity prior to testing.)

10. TEST ARRANGEMENT

10.1 Specimen foundation

The specimen foundation may consist of either a timber beam or a concrete beam. A timber beam shall be at least 90 mm wide and 90 mm deep, with a 20 mm particle board flooring strip attached to its top face with pairs of 60 mm flooring nails at 200 mm centres. A concrete beam shall be of a suitable size to achieve edge distance as the floor it simulates and of a maximum strength of 20 MPa at the time of test.

The specimen foundation shall be securely fixed to the specimen support bed in order that the effects of bending flexibility of these members are eliminated as much as practicable.

10.2 Specimen installation

The method of fixing the base of the specimen to the foundation shall be consistent with that expected to be encountered in service for the intended scope of application.

If installation details are provided as part of the system specification (see Section 8.1), these details shall be used. Where this is not so, the specimen installation shall follow the provisions of NZS 3604 (Table 8.19 for timber floors and clause 7.5.12 for concrete floors).

(Note: Refer to Section 14.4 for alternative anchors for concrete floor slabs.)

(Note: It is recommended that the lining sheet(s) be fixed to the bottom plate only after the bottom plate itself is fixed to the specimen foundation. This is the sequence followed in normal construction practice and prevents potential damage to the sheet caused by the fixings if movement of the bottom plate occurs when fixing it to the specimen foundation.)

10.3 Load application

The attachment of the load application system to the specimen shall be located at mid-length of the specimen to minimise any tilt effects that can occur if the wall rocks under load or has a mechanism that does not restrict the wall's ability to tilt.

10.4 Supplementary uplift restraints

A supplementary uplift restraint shall be used at each end of the test specimen, as shown in Figure 1.

Construction details of the restraint are shown in Figure 2. A bolt or coach screw providing a sliding attachment between the angle and the end of the specimen through a slotted hole is also acceptable. The timber block is to be from the same timber (species and grade) as the frame.

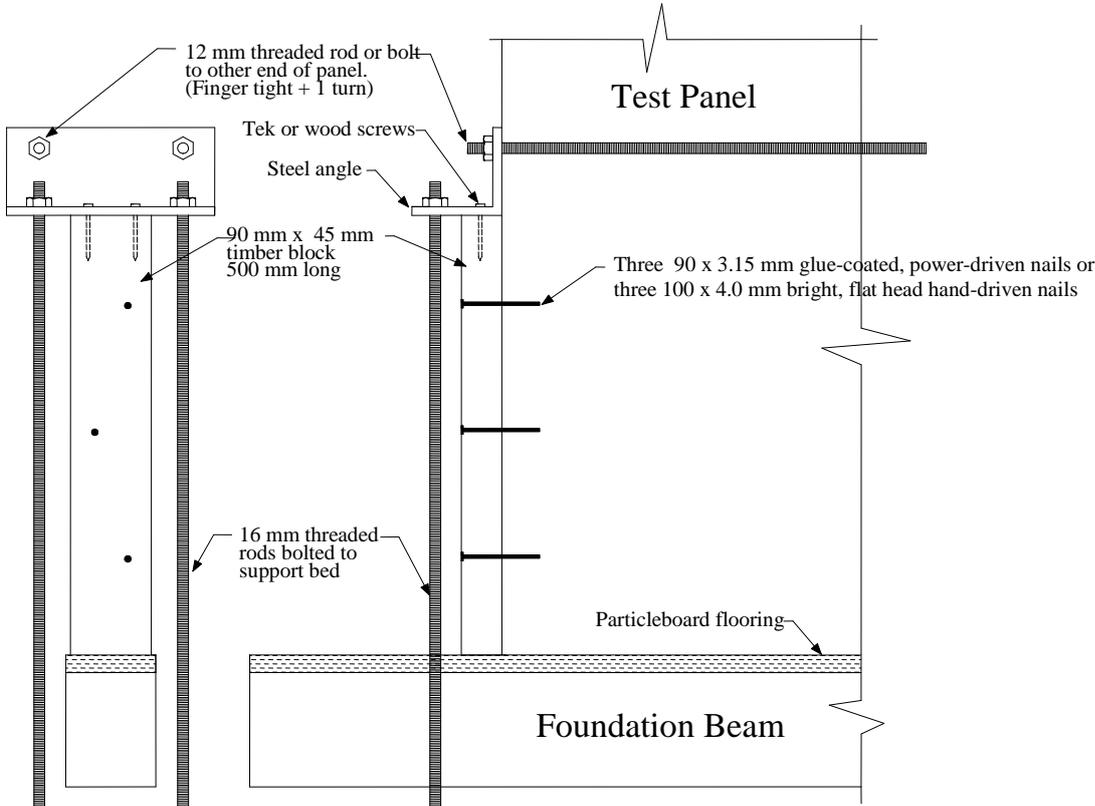


Figure 2. Supplementary uplift restraint

11. TEST PROCEDURE

11.1 Cyclic test loading protocol

Each specimen shall be subjected to three cycles of in-plane displacement at top plate level to each of $\pm(H/300 + 1)$ mm, ± 15 mm, ± 22 mm, ± 29 mm, ± 36 mm and ± 43 mm (where H is the specimen height), as illustrated in Figure 3. Target displacements are to be met within a tolerance of ± 2 mm, measured between top plate and the specimen foundation.

(Note: The specified target top plate displacement of $H/300 + 1$ is to ensure that data will always be available for evaluation at $H/300$, for example, see 6.3.h.)

Where the bracing element is unsymmetrical (for example, see Section 8.2), the first two specimens shall be displaced in the 'weak' direction first and the 'strong' direction second, and the third specimen in the direction giving the lowest result in the first two tests.

The rate of applied displacement shall be within the range 1 to 5 mm per second.

(Note: If sinusoidal displacement is used (with respect to time), the average rate shall be in the range 3 to 4 mm per second)

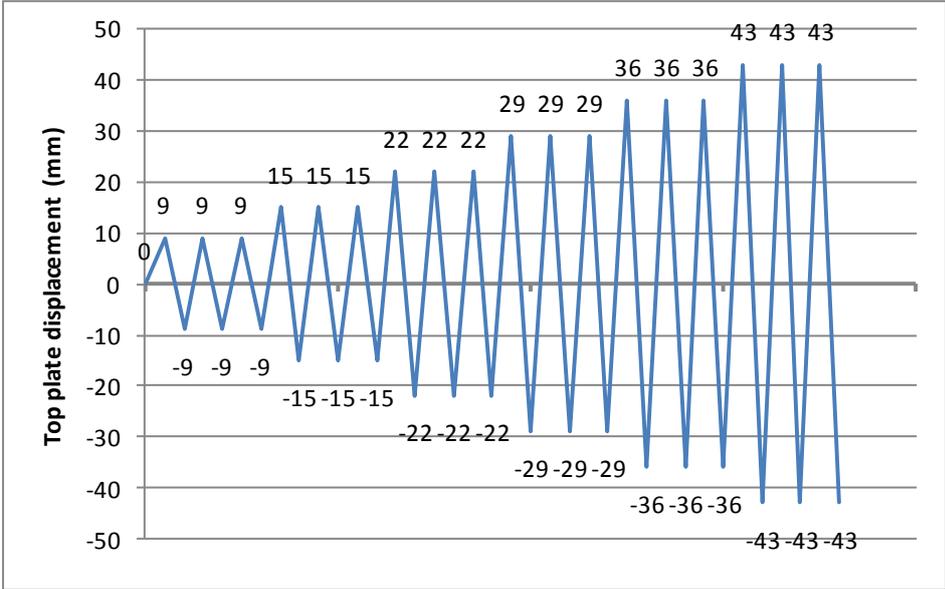


Figure 3. Cyclic load protocol (example shown for a 2,400 mm high specimen)

11.2 Data recording

During the test, measure and record the following data:

- a) The force applied to the specimen, and the relative displacement between top and base of the specimen, sampling at a rate of at least three readings per second.
- b) Observations of the condition of sheet and fasteners that attach the sheathing to the frame.

- c) The dominant mode of deformation and any observed distress or damage in the test specimen.
- d) A description of the mode of failure experienced by the specimen.

12. RESULTS EVALUATION

Nominate a target displacement (from the range 15 mm, 22 mm, 29 mm and 36 mm) that will produce a suitable set of 'push' and 'pull' first and fourth cycle forces for all the tested specimens.

Call this displacement y .

For each specimen:

For the push and pull directions, take the displacement recorded at the end of the 8 mm displacement cycle (i.e. when force returns to zero). Average the absolute values and call this C .

$$K1 = 1.4 - C/8 \leq 1.0$$

If $K1$ is less than 0.8, discard the results from this specimen and substitute another to make up the required set of three. If another specimen fails this criterion as well, the system shall be rated as 'Unacceptable'.

(Note: At SLS loads, a predominantly elastic behaviour is preferred, thereby minimising permanent offsets at this level of load. A modest amount of inelastic behaviour is allowed.)

Take the average of the absolute values of $+P_y$ and $-P_y$ and the average of the absolute values of $+R_y$ and $-R_y$ for each specimen at the nominated displacement $+y$ and $-y$ respectively. Where the value of the load in one direction is more than 20% greater than the load in the other, assign it a value of 1.20 times the lower value before averaging.

Call these values P_y and R_y for each specimen.

Determine the displacement at which each specimen reaches a load of $P/2$ on the first cycle.

Average this displacement for all specimens and call this value d .

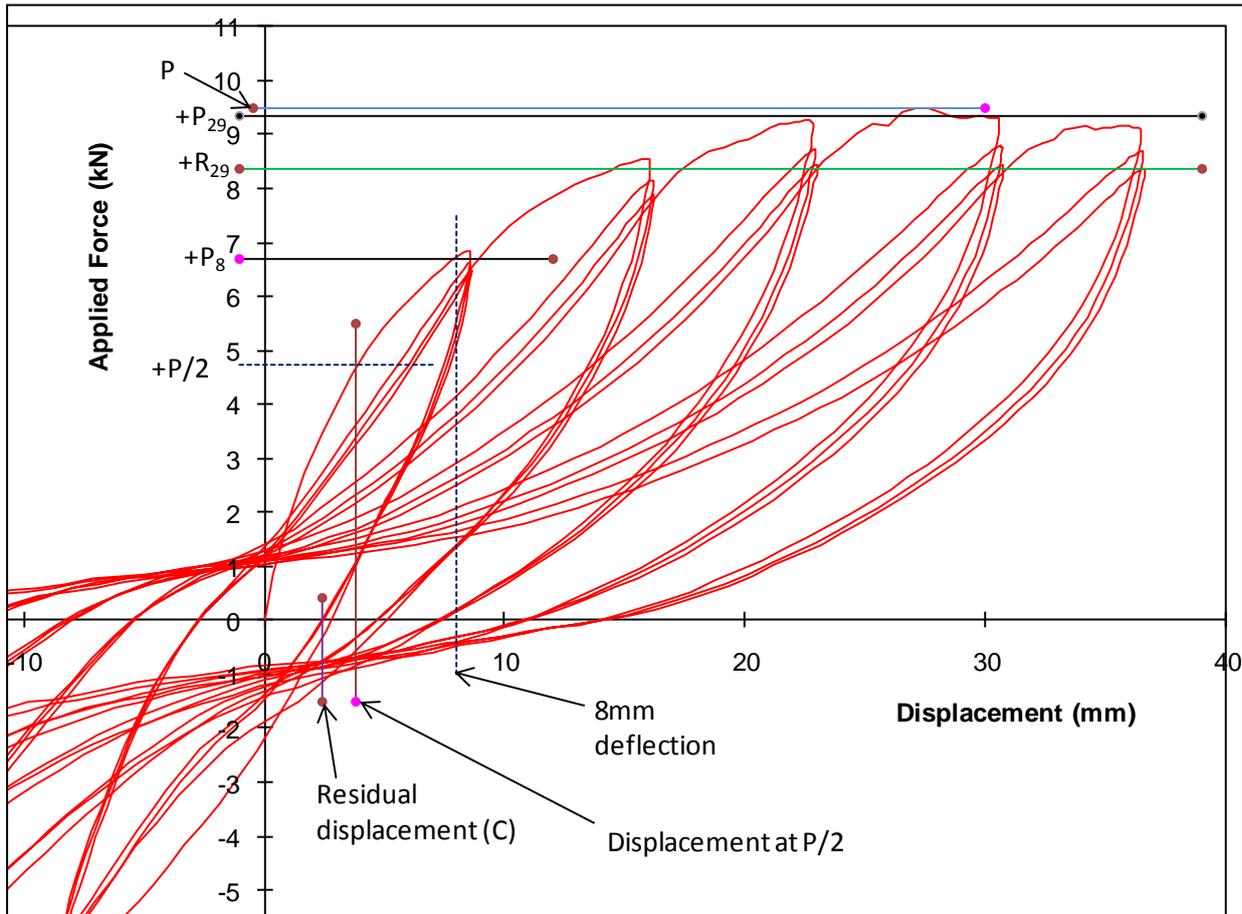


Figure 4. Force and displacement measurements (for $y = 29\text{mm}$)

12.1 Earthquake rating

The ductility of the set of specimens, μ , is defined as y/d . Read off the K4 factor for the test series from Table 1. K4 may be obtained by linear interpolation.

μ	1.0	2.0	2.5	3.0	3.5	4.0
K4	0.35	0.60	0.67	0.74	0.87	1.00

Table 1. K4 factors.

(Note: The derivation of the K4 factors is described in TR10.)

For each specimen, calculate $EQ = K4 \times R_y$.

Compute the earthquake bracing rating BR_{EQ} for each test specimen, in units of BUs, as being 20 times the lesser of the following two values:

- EQ
- $(P_8 \times K1) \times K2/0.55$

where $K2 = 1.2$.

(Note: For the derivation of the value of 1.2 to be used for the systems factor K2, refer to SR 220.)

The earthquake bracing rating for the wall system/element is the average value calculated from the three replicate test specimens. Where the value of BR_{EQ} for any specimen is more than 20% greater than either of the other two specimens, assign it a value of 1.2 times the lower value before averaging.

(Note: The value of 0.55 relates resistance at serviceability limit state to demand at ultimate limit state, as used in NZS 3604. The value was derived from AS/NZS 1170.5 using the following parameters:

Eq	μ	T (sec)	R	k_{II}	
				Class A-D soils	Class E soils
ULS	3.5	0.4	1.0	2.43	2.30
SLS	1.25	0.4	0.25	1.16	1.25

Depending on the values chosen for μ_s and soil class for the site of application, a value from 0.46 to 0.608 can be derived. Considering that the majority of sites will be class A to D and ductility at SLS (up to 8 mm) will be close to 1.25, the value of 0.55 is a compromise value reflecting the accuracy of the assumptions used.)

12.2 Wind rating

Compute the wind bracing rating BR_W for each test specimen, in units of BUs, as being 20 times the lesser of the following two values:

- P_y
- $(P_8 \times K1) \times K2/0.71$

where $K2 = 1.2$.

The wind bracing rating for the wall system/element is the average value calculated from the three replicate test specimens. Where the value of BR_W for any specimen is more than 20% greater than either of the other two specimens, assign it a value of 1.2 times the lower value before averaging.

(Note: The value of 0.71 relates resistance at serviceability limit state to demand at ultimate limit state, as used in NZS 3604. The value was derived from AS/NZS 1170.2 using the following parameters:

Wind	Region W	Region A
V ₂₅	43	37
V ₅₀₀	51	45

The value of 0.71 is between the values calculated for both wind regions and reflects realistic precision considering the accuracy of the assumptions used.)

13. REPORTING

The report shall contain the following information:

1. The name of the testing agency performing the tests.
2. The name of the person responsible for the test.
3. The location and dates over which the testing was undertaken.
4. Full details of the construction specification used, including any limitations that may be placed on the scope of application that may apply to the bracing system. Include full details of the installation specification used.
5. Framing timber type, grade and moisture content.
6. Sheathing type (for example, plasterboard, plywood etc.), thickness and density (if applicable).
7. Sheathing fixings (type, material, shank and head diameter), fixing pattern and edge distances.
8. Curing time for jointing compound (if applicable).
9. Details of the fixing of the bottom plate to the foundation.
10. Details of the means by which uplift of the ends of the specimen is controlled.
11. Description of the mode of failure.
12. Plot of applied load against top plate horizontal displacement.
13. Tabulation of values of P_8 , P_y , R_y .
14. Calculation sheet showing derivation of bracing values for earthquake and wind rating.
15. Photographs and drawings.

(Note: In general, the report should include sufficient detail to enable a third party to duplicate the construction and the testing and produce similar results.)

14. APPLICATION OF BRACING RATINGS

14.1 Use in specifically designed buildings

This procedure produces bracing ratings intended to be compatible with NZS 3604, which applies only to modest sized timber buildings with well distributed structural elements. As a result, the derived BU ratings are not based on characteristic or 'dependable' values as used with other material standards (for example NZS 3603, NZS 3404 etc.) and assume 'typically' distributed bracing elements.

When bracing ratings are used for the specific structural design of a building outside the scope of NZS 3604, equating ratings with loads derived from AS/NZS 1170 together with bracing elements of other materials, engineer designers should be aware of these crucial differences and should make appropriate allowance for the resistance of critical structural elements.

14.2 Use with other than framed, lined walls

This procedure produces bracing ratings for stick-framed timber walls with sheet lining, as stated in Section 1. Testing agencies wishing to use it for other bracing systems should be aware that the K4 factors and the definition used to measure specimen ductility were derived for these types of systems only. Other bracing systems (for example, masonry, steel-framed walls etc.) will have different hysteretic behaviour, thus invalidating the basis of the K4 factors. Use of the test method in these circumstances will require a statement in the test report giving derivation or justification for the K4 factors (or equivalent) used for the analysis.

14.3 Changes to tested systems

The bracing ratings evaluated using this test procedure apply only to bracing walls built in accordance with the test system specifications. Changes to any of the parameters listed in Section 8.1 would render the rating invalid. Therefore, publication of bracing data based on this procedure must give full details of all these parameters, including fixing to the floor (concrete or timber as appropriate).

14.4 Alternative concrete floor anchors

If a timber specimen foundation is used for the test and bottom plate hold down fixings consist of through-bolts or coach screws, suitable alternative concrete anchor fixings must be identified if resulting bracing ratings are claimed for use on a concrete floor slab.

14.5 Maximum bracing ratings

Bracing ratings using this procedure are intended to be constructed in buildings within the scope of NZS 3604. Systems producing high ratings will require resistance to hold down reactions that may not be able to be provided by a typical timber-framed buildings. For this reason, ratings above 110 BU/m for timber floors or 150 BU/m for concrete floors should be published with caution. Refer to NZS 3604.

(Note: This document was written before the revised NZS 3604 was available, so no clause reference is included.)

Ratings derived using this evaluation method may be used for a bracing system of length within two times the tested specimen length. Beyond this, the system behaviour and failure mode is likely to be sufficiently different that a separate test is required.

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