STUDY REPORT

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Installation of domestic windows

S. J. Thurston

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Preface

This is the first BRANZ Ltd investigation into the adequacy of the strength of fixings used to attach windows into New Zealand houses. It is not intended to be an extensive study looking at the total range of possible window sizes, shapes and construction, but rather an initial investigation to determine which parts may be critical. Despite the limited testing some design guidance is provided. In a few critical areas further work is recommended.

Acknowledgments

Dyann Stewart of Aluminium Systems Ltd provided and arranged for installation of the window joinery in the tests described in Section 4. Michael Petersen of National Aluminium Ltd (NALCO) provided the test samples of Section 3.4.2. John Yolland (John Yolland and Associates Ltd) provided the test data used in Section 3.4.1 and gave valuable advice on several issues. Robert Campion of Architectural Profiles Ltd arranged the testing described in Section 3.3 and allowed BRANZ to view and report upon the tests. Graeme Knowles provided some of the photographs used in Section 4.

Note

This report is intended for the Department of Building Housing (DBH) and the Window Association of New Zealand (WANZ). It is expected to also be of interest to all window manufacturers, building inspectors and relevant standards committees.

Note, this report makes use of two reports by John Yolland to WANZ which are detailed in Section 6 References. These reports are not available to the wider public.

Installation of domestic windows

BRANZ Study Report SR242

S. J. Thurston

Reference

Thurston SJ. 2010. ‘Installation of Domestic Windows’. *BRANZ Study Report 242,* BRANZ Ltd, Judgeford, New Zealand.

Abstract

New Zealand houses are using larger windows and are being built on more exposed sites. Double and triple glazing is becoming common and the glass is often placed at an eccentricity of 20 mm to 60 mm from the face of the framing. This report investigates whether the use of the WANZ support bar is able to transfer this eccentric load back to the timber sill trimmer, and whether the sill trimmer will undergo excessive twist due to this loading.

This report also derives the design strength for the staple connection between window frame and reveal and the nailed connection between reveal and window trimming studs. It examines whether standard spacing of these connectors will be adequate to prevent failure in design level windstorms.

Finally this report calculates the design pressure that should be used in prototype window tests to NZS 4211 and compares this with the actual pressures recommended by this standard.

Installation of domestic windows

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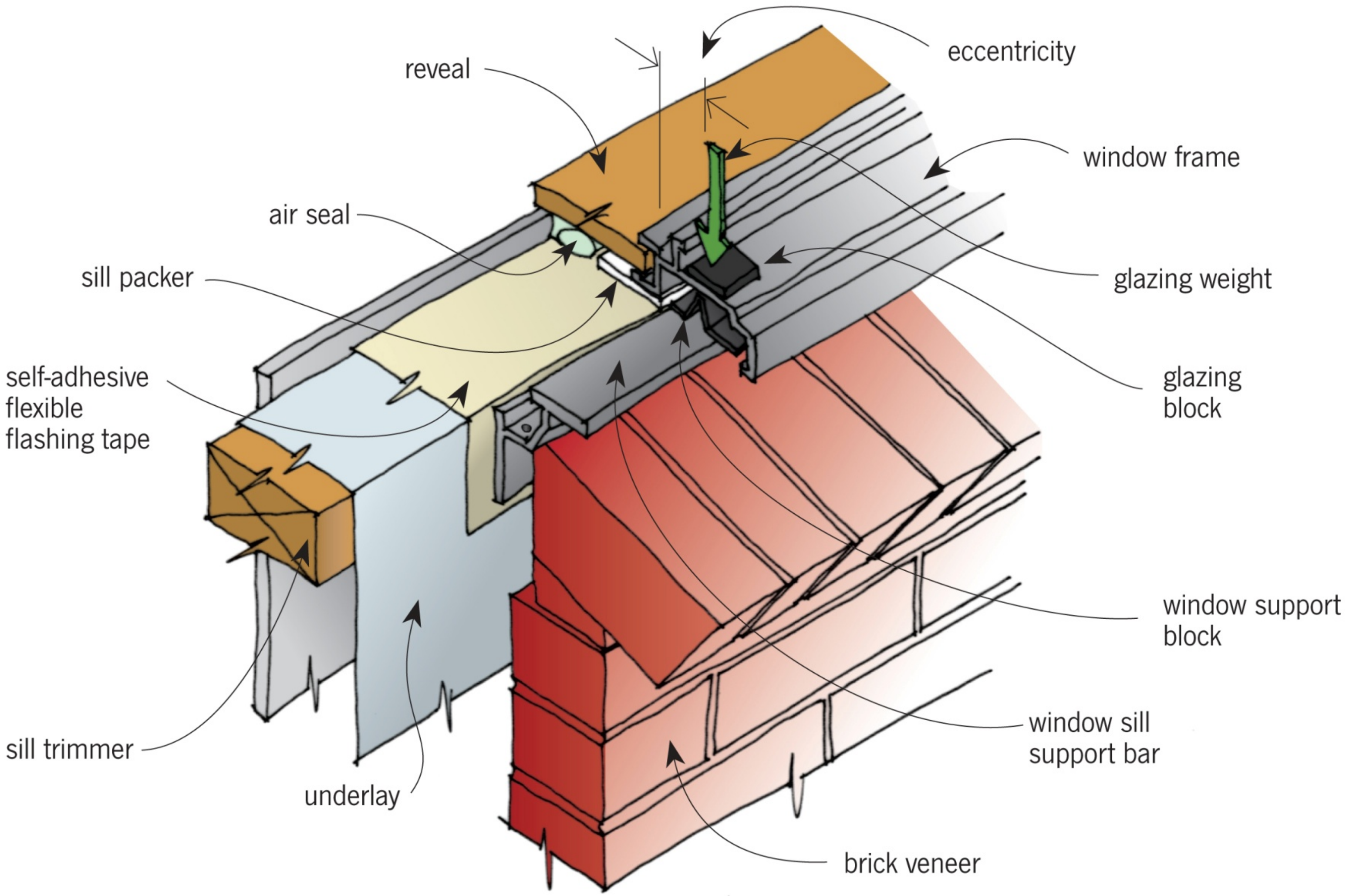


Frontispiece. General view of a window loading on a WANZ bar

1. INTRODUCTION

New Zealand standards give little guidance on the method of fixing domestic windows. This study report examines the adequacy of the construction used to carry the self-weight of the glazing and also the adequacy of the construction used to resist wind face-load. These are discussed in turn below.

1.1 Construction to support glass self-weight

A typical cross-sectional view of a window fitted into a brick veneer wall is shown in Figure 1. It can be seen that the glazing is offset from (i.e. eccentric to) the wall framing. The aluminium window framing is only lightly fixed to the reveal with staples and this connection cannot be relied upon to transmit the glazing self-weight to the reveal. Hence, in situations where there is heavy eccentric glazing the window must be separately supported. Figure 1 illustrates the use of such a support, which in this instance is a WANZ bar. This eccentric load will induce a large tension force in the screw fixing the support bar to the sill trimmer. This report examines whether a proposed new WANZ support bar and fixings are adequate for most window situations.

The sill trimmer will be subjected to a torque load of (glazing load) x (e + D/2) as shown in Figure 2 and may twist under this load. Thus, even if a window support bar successfully carries the vertical load (and torque) back to the window sill trimmer there is no assurance that typical NZS 3604 (SNZ 1999) timber frame construction is adequate to carry the loads without excessive deflection. One purpose of this project is to investigate this issue.

In New Zealand there is a trend for building on more exposed sites and using larger windows which has resulted in thicker glass. The use of double (and soon perhaps triple) glazing is becoming common. This is driven by noise control and the higher insulation demands from the new energy efficiency provisions in the Compliance Document H1 of the NZBC (DBH 2007). Thus, the weight of glazing has increased.

Window glazing is often placed offset from the face of the wall framing due to wall cavities being used between framing and wall cladding. The cavity width typically varies from 20 mm to 60 mm. Cavities have always been used with brick veneer construction, but for other claddings this requirement is being driven by the recent “leaky building” problems.

Thus, window weights have increased and the line of actions of these weights is often offset from the outside face of the wall framing. In some houses problems have occurred due to this eccentric window self-weight. Installation of domestic windows is not covered by any nationally recognised standard. If insufficient window vertical support is provided then the window will experience excessive vertical deflection which may cause leaks in the window joinery.

The Windows Association of New Zealand (WANZ) has recognised the problem and markets a WANZ support bar to carry the window weight back to the timber framing. Other proprietary systems are also available, but these have not been assessed as part of this project. WANZ have advised BRANZ that based on their studies less than 50% of new houses have used the WANZ bar or equivalent window support systems due to their cost. Builders have instead used ad-hoc solutions, which have not always been effective. The WANZ support bar is intended to provide support, ventilation and drainage. WANZ have recently produced a lighter cheaper bar and Section 4.2 discusses tests on this new WANZ bar.

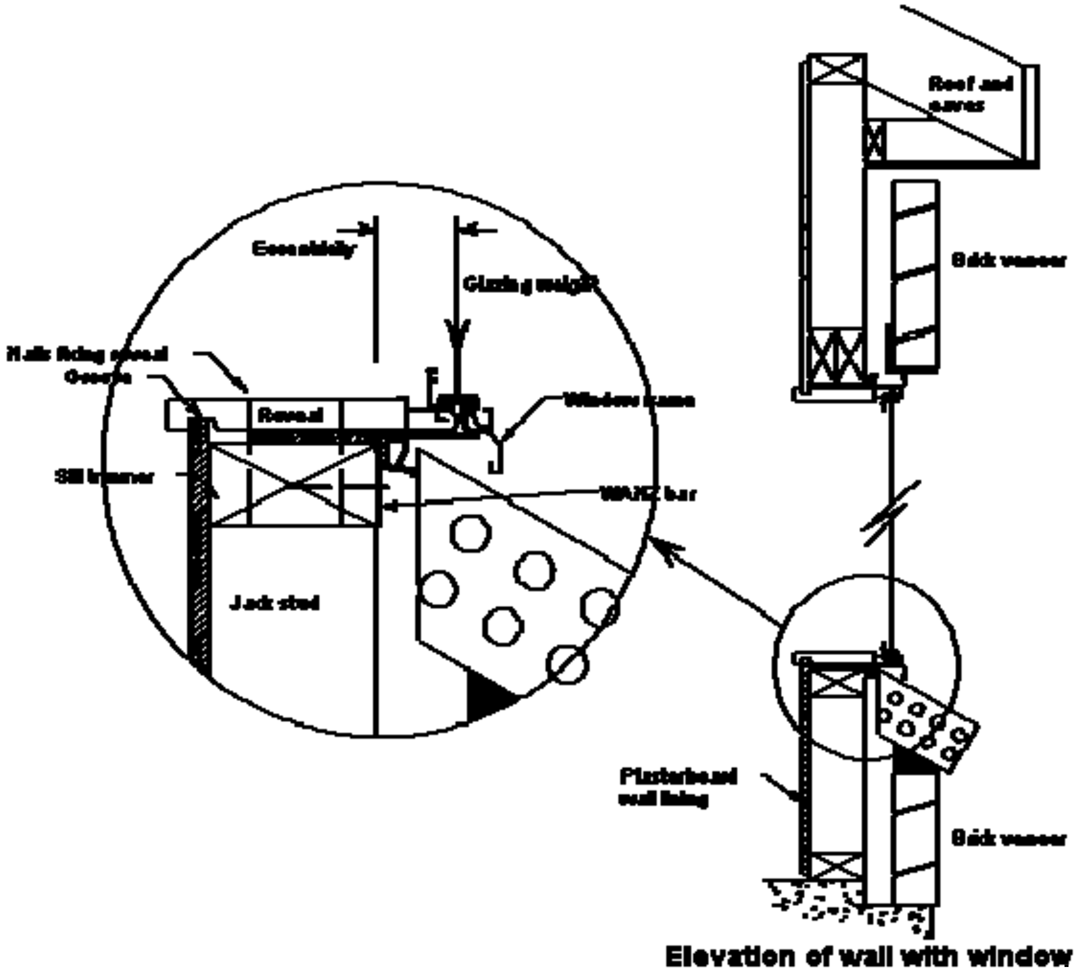


Figure 1. Cross-sectional elevation of a window in a brick veneer wall

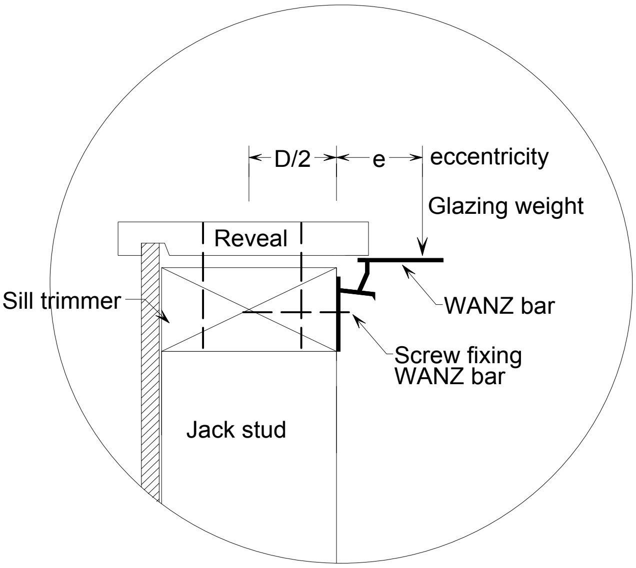


Figure 2. Forces on window support and timber framing due to window self-weight

The Department of Building Housing (DBH) is currently revising the Acceptable Solution E2/AS1 for Clause E2 External Moisture of the New Zealand Building Code (NZBC) (DBH 2005) and has advised the writer that use of the WANZ bar, or a generic alternative, is likely to become mandatory for large eccentric windows. Note that E2/AS1 will contain some claddings requirements previously covered by the standard NZS 3604 *Timber framed buildings* (SNZ 1999). The results of this study are intended to feed into the development of the revision for E2/AS1 (Third Edition, Amendment 5).

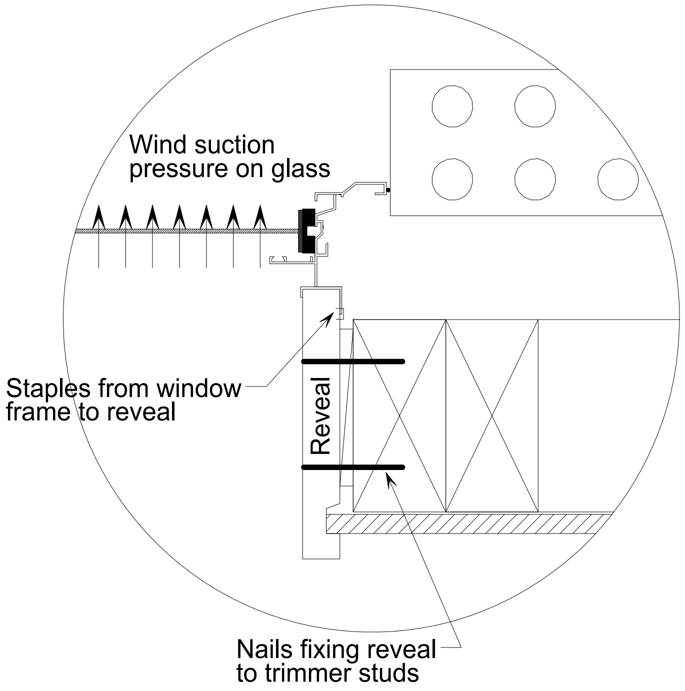
1.2 Fixings to resist wind face-load

The trend to larger windows and construction on more exposed sites places high demands on the connection of windows to wall framing, which are not addressed in NZS 3604. Currently, the structural support for the window unit relies on the knowledge and integrity of the installer. Theoretically, inadequate fixings could result in complete windows being sucked out or blown in under high wind loads.

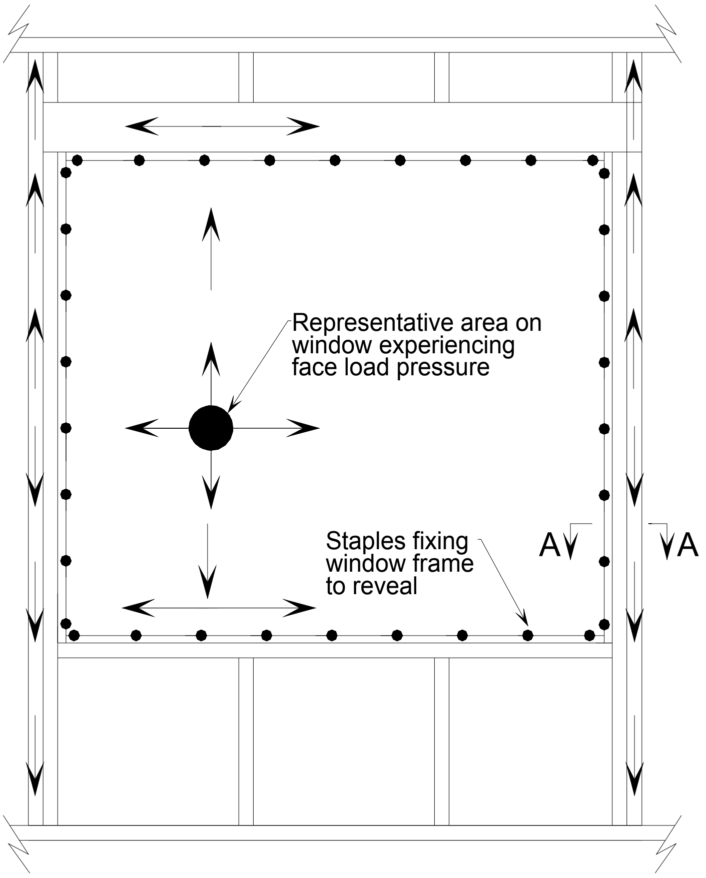
Figure 3(b) illustrates how the wind face-load “suction” forces on glazing are transferred to the wall top and bottom plate. These forces will then be directly or indirectly transferred to the foundations, such as via floor and ceiling diaphragms and bracing walls parallel to the wind forces.

The wind suction forces on the glazing are transferred by the glass itself to the boundary aluminium window frames. The frames are stapled to the window reveal as shown in Figure 3(a) and (b). The force in the reveal is then transferred to the window trimmers as shown in Figure 3(b). This project investigates the adequacy of the strength of the fixing of the window frame-to-reveal connection and also the reveal-to-timber framing connection for the fixings that are currently recommended by WANZ.

The standard specification for performance of windows NZS 4211 *Specification for performance of windows* (SNZ 2008b) is an Acceptable Solution to the NZBC for performance testing of windows and doors, and is particularly related to buildings within the scope of NZS 3604. Most manufacturers achieve compliance with the NZBC by testing window prototypes to NZS 4211. This report calculates the pressures appropriate to such prototype tests and compares these with the test pressures specified in NZS 4211.



(a) Section A-A



(b) Elevation showing timber framing only

Figure 3. Transfer of wind forces on glazing to timber framing

2. PROJECT BRIEF

This study is an initial investigation into the loading and strength of fixings and components to determine which parts may be critical and (within the scope of limited testing) to provide some design guidance. The proposed research is intended to:

1. Test the vertical load and eccentricity limits for the new WANZ window support bar for large windows. (A support bar is likely to become mandatory in the next version of E2/AS1.)

2. Test whether the timber sill trimmer connection details specified in NZS 3604 will carry the window weight at the maximum likely eccentricity, without undue twist of the sill.

3. Determine if the WANZ recommended methods of installing large windows are satisfactory to resist design level face-load pressures in the highest wind zones. The connections of interest are the window frame-to-reveal stapled connection and the reveal-to-wall trimmer nailed connection. These connection details are not currently specified in building standards.

4. Examine the magnitude of the face-load pressures currently used for testing prototype windows.

3. OUT- OF-PLANE LOADING

3.1 Brisbane storm

The following experience in a recent storm indicates that current practice may not be satisfactory.

Leitch et al (2009) describe damage to houses following two recent storms in Australia. The peak gust wind speed for both events was estimated to be less than the current design wind speed for Brisbane. Some windows were not adequately fixed to the supporting structural members resulting in complete windows being “blown in”. They recommended that the fixing details of windows to the surrounding structure should be specified and that these must be strong enough to resist the design wind loads. It was also found that flying debris sometimes broke windward windows causing a sudden increase in internal pressure. This could lead to subsequent failure of windows on the leeward side as windows on this side would be subjected to both an external “suction” and internal positive pressure. However, the authors did not report any windows being “sucked” out in the Australian windstorms.

3.2 Window glass design methodology

Table 1 of NZS 4223.4 *Glazing in buildings. Part 1: Glass selection and glazing* (SNZ 2008d) provides the design level ultimate wind pressures to be used to design glass for windows for New Zealand buildings. The values given in Table 1 of this report are the same as the pressures derived in Section 3.3.2.

For given ultimate design pressures, NZS 4223.4 gives the maximum window size for various glass types and support conditions. These values were based on finite element analysis using the design capacity of glass flexural strength for each particular glass type.

NZS 4223.1 *Glazing in buildings. Part 4: Wind, dead, snow and live actions* (SNZ 2008c) requires that the design capacity of the glass shall be $øR_u$ where ø = capacity reduction factor = 0.67 and R_u is the short-term (wind load) characteristic, lower 5 percentile, flexural strength of a particular glass. Thus, the procedure for glass takes into account the variability of glass strength to ensure that failure of glass is unlikely when subjected to the ultimate design pressure in a particular window.

3.3 Prototype test pressures for windows and glazing

3.3.1 Background

NZS 4211 *Specification for performance of windows* (SNZ 2008b) is a standard for the performance testing of windows so that they may be certified as complying with the wind zones specified in NZS 3604 (SNZ 1999). Table 5 of NZS 4211 specifies the ultimate limit state (ULS) test pressures. Section 3.3.2 of this report examines if these test pressures are correct.

NZS 4211 only tests the portion of the construction from the window frame inwards. It does not test the connection between frame and reveal or reveal and window trimmers. Such connections are tested in AS/NZS 4284 *Testing of building facades* (SNZ 2008a). However, tests to AS/NZS 4284 are not required for house windows. On the other hand, tests to the NZBC E2/VM1 test procedure (the Verification Method for E2/AS1) are for the complete system including wall, window and connections, but only up to 500 Pascals, as E2/VM1 is only intended to test for window watertightness.

3.3.2 Calculation of design pressures for glass

Design wind pressures for the design of glazing are calculated below based on specifications of the New Zealand loading code AS/NZS 1170.2 (SNZ 2002a). The terminology used is defined in AS/NZS1170.2.

From Eqn 2.4(1) of AS/NZS 1170.2 the design wind pressure $p = 0.6V^2 \times C_{fig} \times C_{dyn}$
$C_{dyn} = 1$. A value called q_z is hereby defined as $q_z = 0.6V^2$.

Therefore, $p = q_z \times C_{fig}$ .... (1)

The value of C_{fig} is calculated below for both the positive and negative pressure cases.

(a) Pressure acting in the inward direction (positive pressure)

From Eqn 5.2(1) of AS/NZS 1170.2:

$C_{fig} = C_{pe}K_aK_CK_LK_P$ for external pressures and $= C_{pi}K_C$ for internal pressures
$K_a = K_C = K_P = 1$ for windows
$K_L = 1.25$ for windows anywhere on the windward wall
$C_{pi} = -0.3$ from Table 5.1(A) of AS/NZS 1170.2
$C_{pe} = 0.7$ from Table 5.2(A) of AS/NZS 1170.2

Hence, $C_{fig} = (0.7 \times 1.25 – (- 0.3)) = 1.175$ .... (2)

i.e. $p = q_z \times C_{fig} = 1.175\ q_z$ .... (3)

(b) Pressure acting in the outward direction (negative pressure)

$K_a = K_C = K_P = 1$ for windows
$K_L = 2.0$ for side windows within 0.5a of a corner (where 'a' = 0.2 times min of the length of the walls or the eaves height = 2.4 m say)
$C_{pi} = 0$ from Table 5.1(A) of AS/NZS 1170.2. (It could be argued that a more severe value of 0.2 or 0.6 may be more appropriate if the front wall windows have been broken by flying debris.)
$C_{pe} = -0.65$ from Table 5.2(A) of AS/NZS 1170.2
Hence, $C_{fig} = (-0.65 \times 2 + 0.0) = -1.3$ .... (4)

i.e. $p = q_z \times C_{fig} = -1.3\ q_z$ .... (5)

Table 1 gives glazing design wind pressures for various wind zones and was calculated using Eqn (3) and (5) and from the definition of q_z.

Table 1. Design wind pressures for glazing for various NZS 3604 wind zones

Wind zone	Wind speed	q_z (kPa)	ULS[1] design positive pressure (kPa)	ULS[2] design negative pressure (kPa)
Low	32 m/s	0.62	0.72	-0.80
Medium	37 m/s	0.82	0.96	-1.06
High	44 m/s	1.16	1.36	-1.50

Legend:
1 Design positive glazing pressures for windows located anywhere as calculated above and also as given in Table 1 of NZS 4233.4. These are also the same as the test pressure in Table 5 of NZS 4211.
2 Design negative (suction) glazing pressures for windows on side walls located within 2.4 m of a corner as calculated above and also as given in Table 1 of NZS 4233.4.

3.3.3 Proposed test pressures for windows in NZS 4211

The test pressures for windows given in Table 5 of NZS 4211 are the same as used for glazing under positive wind pressure as given in the fourth column, labelled ULS[1] in Table 1 of this report i.e. they are based of Eqn (3). The writer considers that this is incorrect and that the test pressures should factor up that used for glazing to account for the variability as required by Appendix B of AS/NZS 1170.0. This is to ensure a particular window in a particular building is unlikely to fail at the ultimate design pressure.

A variability of 15% has been assumed in the calculations below. It is recognised that the result is sensitive to the variability assumed and the value chosen is likely to be subject to robust debate.

From AS/NZS 1170.0 (SNZ 2002a) Table B1:

Test pressure = $1.79p_d$ for a single test sample having 15% variability
i.e. Test suction pressure = $1.79 \times (-1.3q_z) = -2.33q_z$ .... (6)

From a comparison of Eqn (3) and (6) it can be seen that the proposed test pressures are 2.33/1.175 = 1.98 times the values in Table 5 of NZS 4211. Hence, it is concluded that the test pressures specified in NZS 4211 are too low.

3.4 Strength of connection between window and wall framing

The following tests were undertaken:

1. A full scale out-of-plane "suction" pressure test to check the connection between window reveal and window trimmers as described in Section 3.4.2 and window frame and window reveal as described in Section 3.4.1.
2. Elemental tests to determine the design strength of the stapled connection between window frames and liner (reveal) for coated and stainless steel staples and for different reveal material for wind "suction" loading are described in Section 3.4.1. The distribution of staple shear forces is estimated by a structural analysis and the results compared with the calculated staple design strength in Section 3.4.4.
3. Elemental tests to determine the design strength of the nailed connection between window reveals and window trimmers are described in Section 3.4.2. The demand load is compared with the design level connection strength.

3.4.1 Tests measuring the strength of the staple connection between window frame and liner (reveal)

Yolland (2007b) tested the connection strength of staples fixing window frames to reveals for out-of-plane wind "suction" loading. A total of 10 samples was tested for each combination of the following three variables:

1. Two types of staples: 15 x 10 mm staples made of zinc-coated steel and 15 x 8.7 mm stainless steel.
2. Three different reveal materials.
3. Staple direction both parallel and transverse to an aluminium window frame edge.

Only the test results for construction where the staples were transverse to the edge are used here as this is the common practice and causes less timber splitting than placement of staples parallel to the edge. Although the test loading was for the staple in shear, the failure that occurred was actually withdrawal of one staple leg.

The staple characteristic strength, R_{staple}, calculated from Yolland's test results but using the BRANZ EM1 method (BRANZ, 1999), is given in Table 2. Note that any deterioration of staple fixing strength with time, such as corrosion of the staples or decay of the reveal, will reduce these characteristic strengths.

Table 2. Calculation of staple characteristic shear strength R_{staple}

Reveal material	Staple type	Mean load (N)	Standard Deviation (N)	Coefficient of Variation υ	$P_{0.05}$ 5th percentile (N)	R_{staple} Characteristic Strength (N)
Pine	Coated	456	95	0.208	299	246
Rimu	Coated	652	87	0.133	508	451
Dynaboard	Coated	651	88	0.135	506	447
Pine	SS	700	58	0.083	604	562
Rimu	SS	618	30	0.049	569	545
Dynaboard	SS	730	83	0.114	593	535

Legend:

SS means the staple material was stainless steel

Coated means the steel staples were zinc-plated

$R_{ek} = (1 - \frac{2.7v}{\sqrt{n}})P_{0.05}$ = characteristic residual strength

$$P_{0.05} = mean - 1.$$

65σ = 5th percentile of measured data
$v = \frac{\sigma}{mean}$ = coefficient of variation of the individual values
σ = standard deviation of individual values
n = number of samples = 10

3.4.2 Tests measuring the strength of the nailed connection between liner (reveal) and window trimmers

To measure the shear strength of the reveal-to-window trimmer nailed connection, 10 test specimens (Figure 4) were loaded so that the connection was in pure shear.

Each reveal was nailed to a stud using four 75 x 3.15 jolt-head galvanised nails though plastic spacers as shown in the test photographs in Figure 5 and Figure 6. This created a 7 mm gap between stud and reveal. Two reveals were then glued together to form one symmetrical test specimen as shown in Figure 4 and Figure 5. Thus, each specimen consisted of two lengths of reveal and two lengths of trimming stud and used eight nails.

Figure 4. Photograph of the test specimen showing the two studs and two reveals glued back to back (taken before the shear test)

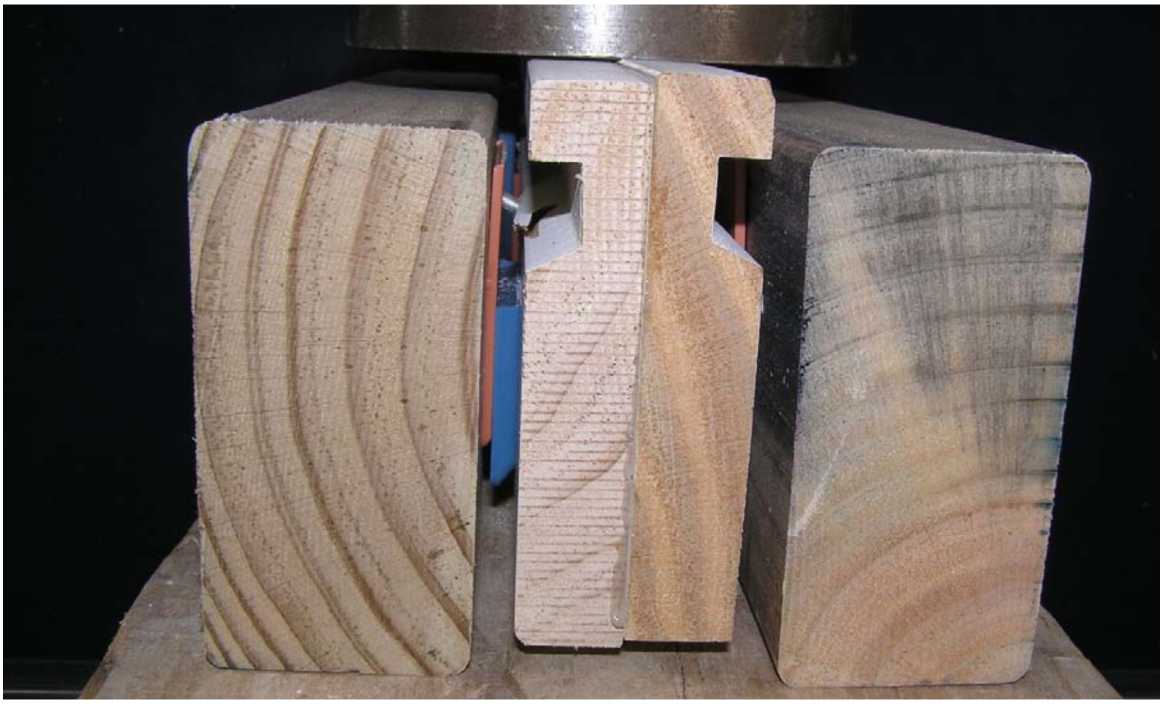


Figure 5. Photograph of the test specimen showing the nailed connection between reveal and stud (taken after the shear test)

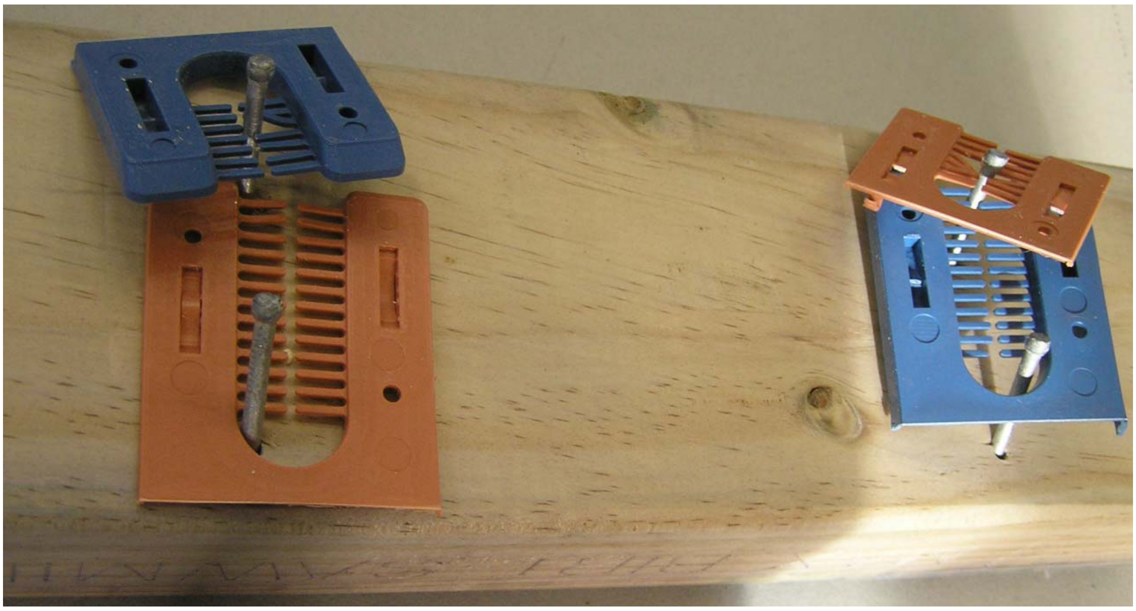


Figure 6. Nails used to connect window reveal and window trimmers. *Plastic spacers used between reveal and trimmers to form a 7 mm gap can be seen. For the purpose of this photograph, the reveal has been prised off, during which time the nail heads pulled through the reveal.*

The top and bottom edges of the members were offset, as shown in Figure 4, so that when a vertical load was placed on the edge of the reveals, the entire load was transferred through the nails and then into the studs. This is a similar load path as occurs when wind pressure on a window is transferred from reveals to trimming studs.

When the specimens were loaded, the nails deformed by bending in the gap between reveal and stud. Elsewhere, the nails remained straight. The nails did not pull out of the timber and the jolt-head did not pull through the reveal. Note that the nail jolt-head had a diameter of 4.7 mm.

The load versus displacement test results from all tests is given in Figure 7. The loads in Table 3 have been calculated for the maximum load the specimen resisted as well as the load at 2 mm and 5 mm displacement. The values given are for the total applied load divided by the number of nails (8) to give a representative characteristic strength per nail (R_{nail}).

Table 3. Strength of nailed connection between window reveal and window trimmers

	Load in kN at the following deflections		**Maximum load**
	2 mm	**5 mm**	**(kN)**
No 1	0.523	0.763	1.271
No 2	0.481	0.713	1.186
No 3	0.461	0.716	1.330
No 4	0.454	0.609	1.006
No 5	0.588	0.819	1.362
No 6	0.494	0.678	1.125
No 7	0.538	0.779	1.307
No 8	0.364	0.564	1.106
No 9	0.503	0.756	1.382
No 10	0.364	0.564	1.003
average	0.477	0.696	1.208
Sdev (σ)	0.071	0.090	0.143
C.o.V. (ν)	0.149	0.130	0.118
$P_{0.05}$	0.360	0.547	0.973
R_{nail}	0.314	0.486	0.874

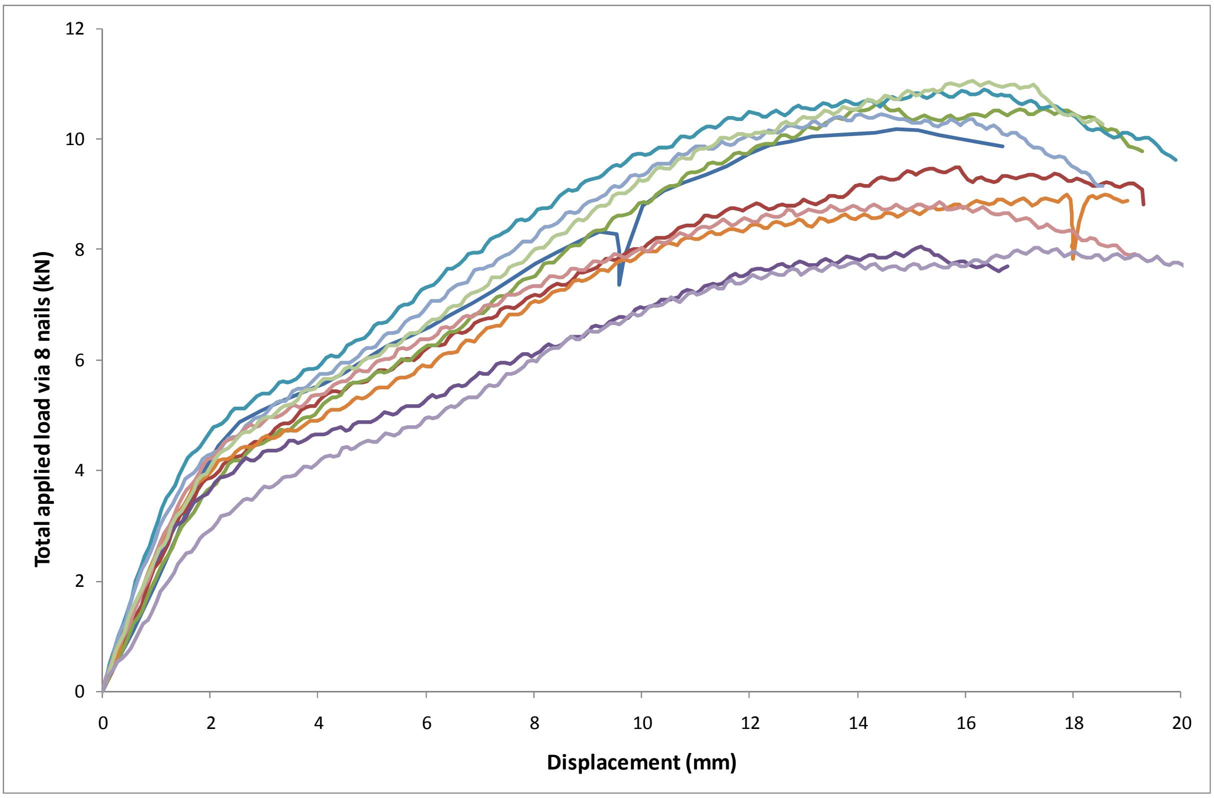


Figure 7. Total applied load versus displacement in the nailed reveal-to-trimmer stud connection shear test

The ULS design force on a window, from Section 2.5.3.1 of AS/NZS 1170 Part 2 (SNZ 2002b), is (window area) x W_{ULS} where W_{ULS} is the ULS differential pressure. This force must be resisted by the sum of the nails connecting the window frame to the reveal.

If it is assumed that all nails are equally loaded, then in the ULS case the nail shear load $F_{nail} = W_{ULS} L_W H_W / N$, where W_{ULS} is the design suction pressure given in the last column of Table 1, L_W is the window length, H_W the window height and N is the total number of nails used.

The design resistance of a single nail is given by ø x R_{nail} where ø is the strength reduction factor and R_{nail} is the characteristic nail strength from Table 3. Section 2.5 of NZS 3603 (SNZ 1993) gives ø = 0.7 for this situation. For a satisfactory design, the design resistance must be greater or equal to the design action.

$$\text{Thus, } ø \times R_{nail} \geq W_{ULS} \times L_W \times H_W / N \text{ .... (7)}$$

It the reveals are fixed to the studs with a single nail at 150 mm from corners and thereafter at 450 mm centres the number of nails used is approximately $n \approx 2(L_W \times H_W)/0.45 + 4 = 4.44(L_W \times H_W)+4$.

$$\text{Thus, } 0.7 \times R_{nail} \geq W_{ULS} \times L_W \times H_W / (4.44(L_W \times H_W)+4) \text{ .... (8)}$$

However, serviceability limit state (SLS) concerns may influence the nail design load in Table 3 and also gives R_{nail} values for an assumed 2 mm deflection limit and a 5 mm deflection limit. AS/NZS 1170.0 (SNZ 2002a) recommend using a 25-year return period for the SLS case and a 500-year return period for ULS wind loads. AS/NZS 1170.2 (SNZ 2002b) divides New Zealand into two wind regions called W and A7. From Table

3.1 of AS/NZS 1170.2 the ratio of SLS/ULS wind speeds is 43/51 = 0.843 for Region W and 37/45 = 0.822 for Region A7. The former is more critical in this instance as the exercise is to maximise the demand serviceability wind pressures. Thus, W_{SLS}/W_{ULS} = 0.843^2 = 0.711.

The limits for L_W and H_W are plotted in Figure 8 for single nails being placed at 450 mm centres and Figure 9 for nails being placed in pairs. Assumptions used in deriving these graphs were:

1. W_{ULS} = 1.93 kPa (very high wind from Table 1) and W_{SLS} = $0.711W_{ULS}$. R_{nail} values for were taken from Table 3.
2. Nail spacing = 450 mm starting at 150 mm from a corner.
3. The sill trimmer and lintel connection strengths to the trimming studs is adequate to transfer the wind loads.

Window length and width combinations that fit on or under the limits plotted in Figure 8 and Figure 9 are deemed to be satisfactory. Thus, the graphs indicate that for average-sized windows single nailing will be adequate. These graphs were based on the unconservative assumption that all nails were equally loaded. However, it is expected that few problems will occur if pairs of nails are used at 450 mm centres for most windows but are closed up to 300 mm centres in high wind zones for very large windows – say for those with an area greater than 6 m^2.

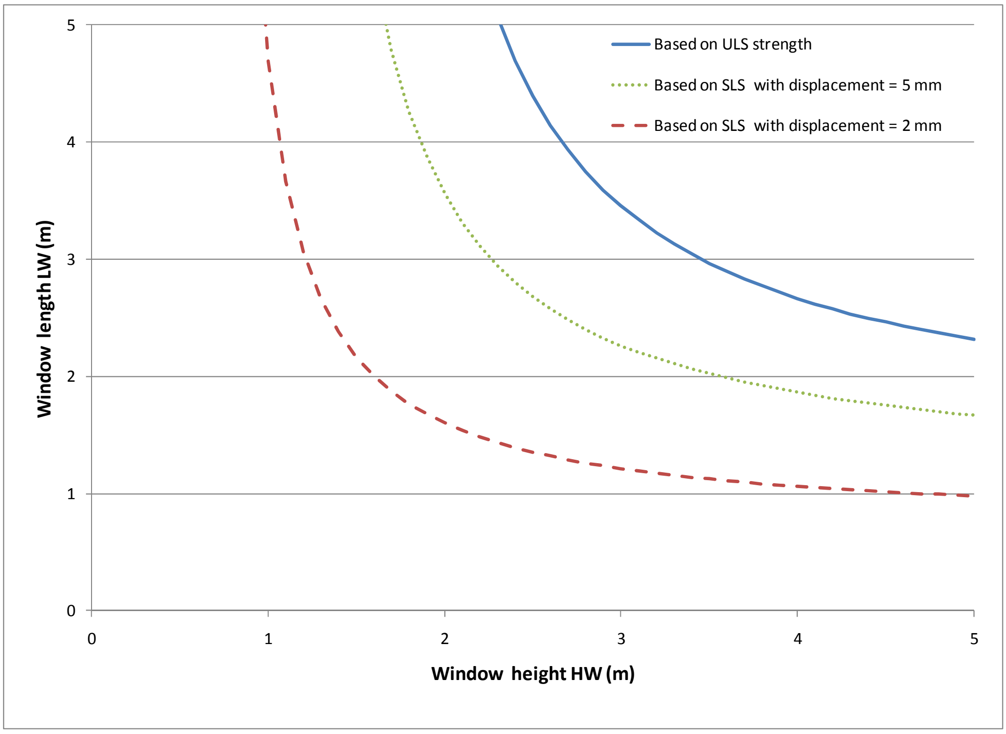


Figure 8. Window height and width limitation based on the design level reveal-to-trimmer nail strength for single nails at 450 mm centres

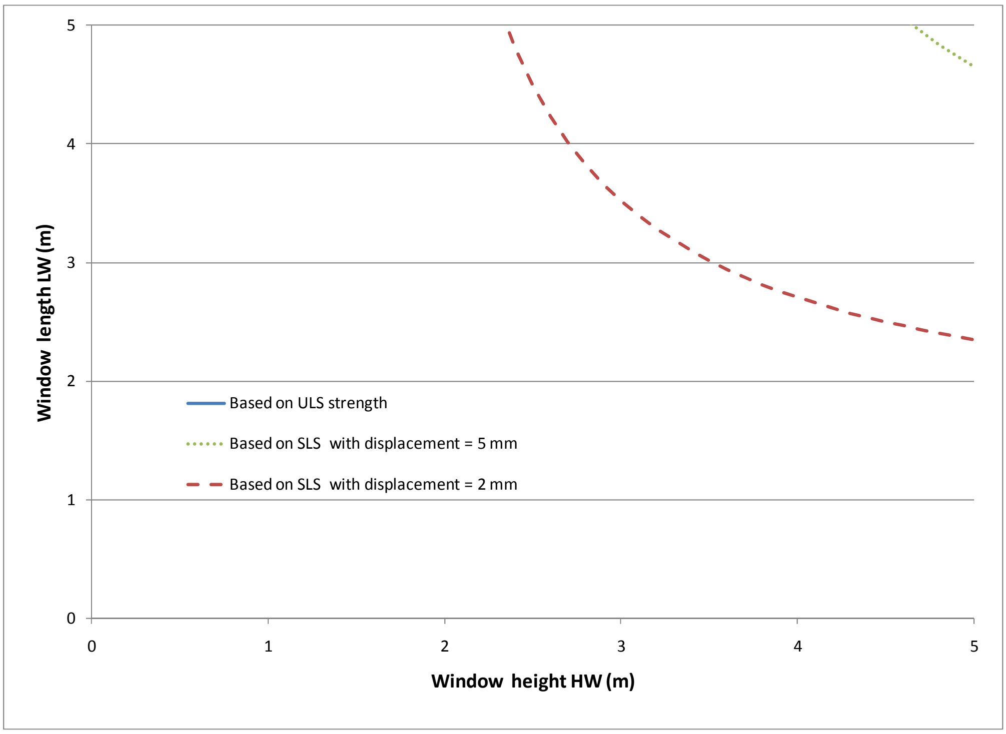


Figure 9. Window height and width limitation based on the design level reveal-to-trimmer strength for pairs of nails at 450 mm centres

3.4.3 Out-of-plane pressure test of window fitted into a weatherboard clad wall

E2/VM1 is a Verification Method for determining compliance of window and doors to NZBC E2.3.2. This method states that windows and doors must be tested to NZS 4211 to the appropriate wind zone design pressure.

A full E2/VM1 test on a weatherboard clad wall incorporating a 1600 mm wide by 1200 mm high aluminium framed window (Figure 10) was tested at Hamilton on 9 March 2010 by John Yolland from Yolland and Associates Ltd. The window used the new WANZ support bar system and had finger-jointed radiata pine reveals. After the NZS 4211 test, the suction pressure (i.e. in the direction pushing the wall outward) was increased to the maximum simulated wind suction pressure the centrifugal fan could impose.

The reveals were nailed to the trimming studs with 75 x 3.15 mm galvanised steel jolt-head nails at 150 mm from corners and thereafter at 450 mm centres. At each nail location, a plastic spacer was used between the window frame and window trimmers so that the gap between the two was approximately 7 mm wide (see Figure 6). This nail type and spacing and maximum gap may be specified in the E2/AS1 revision (yet to be finalised).

The aluminium window frame extrusion was stapled to the reveal with stainless steel staples positioned at 50 mm from window corners and then at 200 mm centres. The writer was advised that the staple dimensions were what is planned to be specified the E2/AS1 revision. A typical photograph of the staples is shown in Figure 11. They were loaded in shear during the test.

The test specimen withstood 4 kPa differential “suction” pressure with no visible signs of damage. This is an average staple force, $F_{MeanStaple}$, of:

$F_{MeanStaple}$ = 4000 x 1.6 x 1.2/(30 staples) = 256 N/staple.

As $F_{MeanStaple}$ is well below the design shear strength for the stainless steel staple in pine given as 562 N in Table 2, it is not surprising that no staples pulled out at the 4 kPa maximum test pressure.

The average shear force/nail fixing from reveal-to-trimming studs, $F_{MeanNail}$ is given by:

- $F_{MeanNail}$ = 4000 x 1.6 x 1.2/(8 nails) = 960 N/nail if it is assumed that all the window face-load is directly transferred to the trimmer studs.
- $F_{MeanNail}$ = 4000 x 1.6 x 1.2/(18 nails) = 427 N/nail if the face-load is also equally transferred to the sill and lintel trimmers. However, the face-load in the sill and lintel must then be transferred to the trimming studs by end nail connection which may be a weak link.

Table 3 of Section 3.4.2 gives the ultimate characteristic strength (R_{nail}) of a nail fixing a reveal to trimmer studs as 0.874 kN i.e. 874 N/nail. As $F_{MeanNail}$ of 427 N/nail is well below this characteristic strength it is not surprising that no nails failed at 4 kPa pressure.

A window having a greater area than that tested but of the same length:width ratio will increase the demand load per fixing when subjected to the same differential pressure as the number of fixings increases linearly with scale, whereas the total wind force will increase with the scale squared.

Figure 10. View of window in weatherboard clad walls in the Hamilton test

Figure 11. Typical reveal-to-window frame stapling used in the Hamilton test

3.4.4 Theoretical analysis of the forces in the staple connection between window frame and liner (reveal)

The glass can transmit the wind load in two directions as shown by the arrows in Figure 12. The staples fixing the window frame to the reveal are shown in small black circles and are assumed to be at 0.2 m centres. The actual load path is complex and the distribution of staple forces depends on the relative stiffness of the components, including the timber framing members and the aluminium window frame. Load transmitted to the sill or lintel trimmers is expected to be transferred to the trimming studs. However, this load transfer may be limited by the strength of the end nailing strength of the sill or lintel to the trimming studs.

Section 4.4.4.2 of NZS 3603 (SNZ 1993) allows the design strength of connections containing 50 or more nails to be factored by 1.3. The factor for fewer nails can be obtained by linear interpolation assuming a value of 1.0 for only four nails. However, (1) as the subject is staples not nails, (2) as the number of staples varies with window size and (3) because staple failure can occur by unzipping, the factor is assumed to be 1.0 in the analysis below. However, this assumption is recognised as being conservative.

To predict the distribution of staple forces around a window frame, a structural analysis using the Space Gass computer package was performed on a model including the window and adjacent timber framing. A 1 kPa uniform suction pressure was applied to the glass. The window size was L_W = 1.7 m and H_W = 1.5 m and the number of staples, n, = 34.

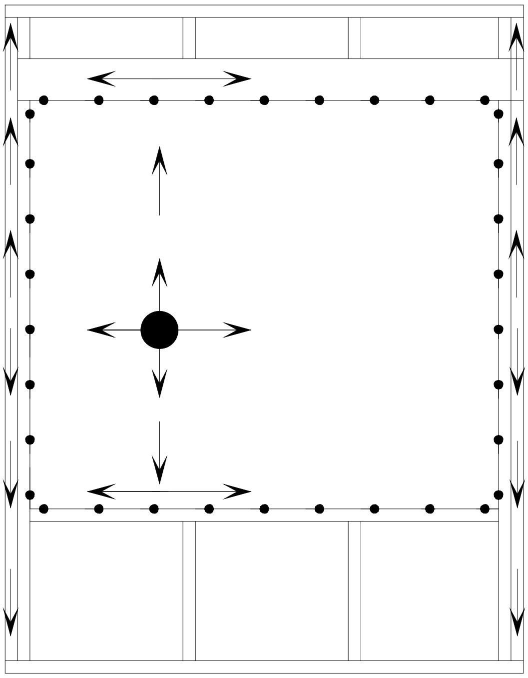


Figure 12. Load transfer paths of wind suction forces on a window

The window was modelled by a fine mesh of plate elements to represent 6 mm thick glass. The window frame section was assumed to have a major axis stiffness of 87,000 mm^4. Timber was assumed to be MSG 8 radiata pine and the typical member and reveal sizes used were as given in Section 4.2.2. The sill and lintel trimmers were assumed to be pinned at the intersection with the trimming studs, and the trimming studs were assumed to be pinned to fully restrained top and bottom plates. The framing around the windows included the reveals. The glass finite element mesh was pinned at the edges and thus could not transmit bending moment directly to the window frame.

Staple forces calculated by Space Gass computer model are plotted around the perimeter of the rectangular window frame in Figure 13. The small circles drawn on the window frame are the staple locations. Staple outward shear forces are plotted on the inside of the frame and staple inward shear forces on the outside. These are drawn with a dotted line along the trimming studs and a dashed line along the lintel and sill trimmers. Note the change in the staple shear forces from outward to inward on the trimmer studs near the window corners.

The ULS design force on a window, from Section 2.5.3.1 of AS/NZS 1170 Part 2 (SNZ 2002b), is (window area) x W_{ULS} where W_{ULS} is the ULS differential pressure. This force must be resisted by the sum of the staples connecting the window frame to the reveal.

The lowest maximum staple load is if all staples are loaded uniformly when the staple shear load $F_{mean} = W_{ULS}L_WH_W/n$, where W_{ULS} is the design suction pressure given in the last column of Table 1, L_W is the window length, H_W the window height and n the total number of staples used. However, as the staples are loaded non-uniformly, the peak staple shear load = K x F_{mean} where K is yet to be determined.

The 1 kPa modelled applied window pressure over the window area gives a total applied load of 1.5 x 1.7 x 1 = 2.55 kN. The average staple demand shear force, F_{mean}, = 2.55/(34 staples) = 0.075 kN and this of course corresponds with the average of all staple loads from the computer analysis plotted in Figure 13. However, the peak staple shear demand force was 0.334 kN = 0.334/0.075 x F_{mean} = 4.46 x F_{mean} and occurred at Point B along the sill trimmer. At Point A along the lintel it was 2.42 x F_{mean}. Near mid-length of the window frame sides the maximum staple load was 1.87 x F_{mean}.

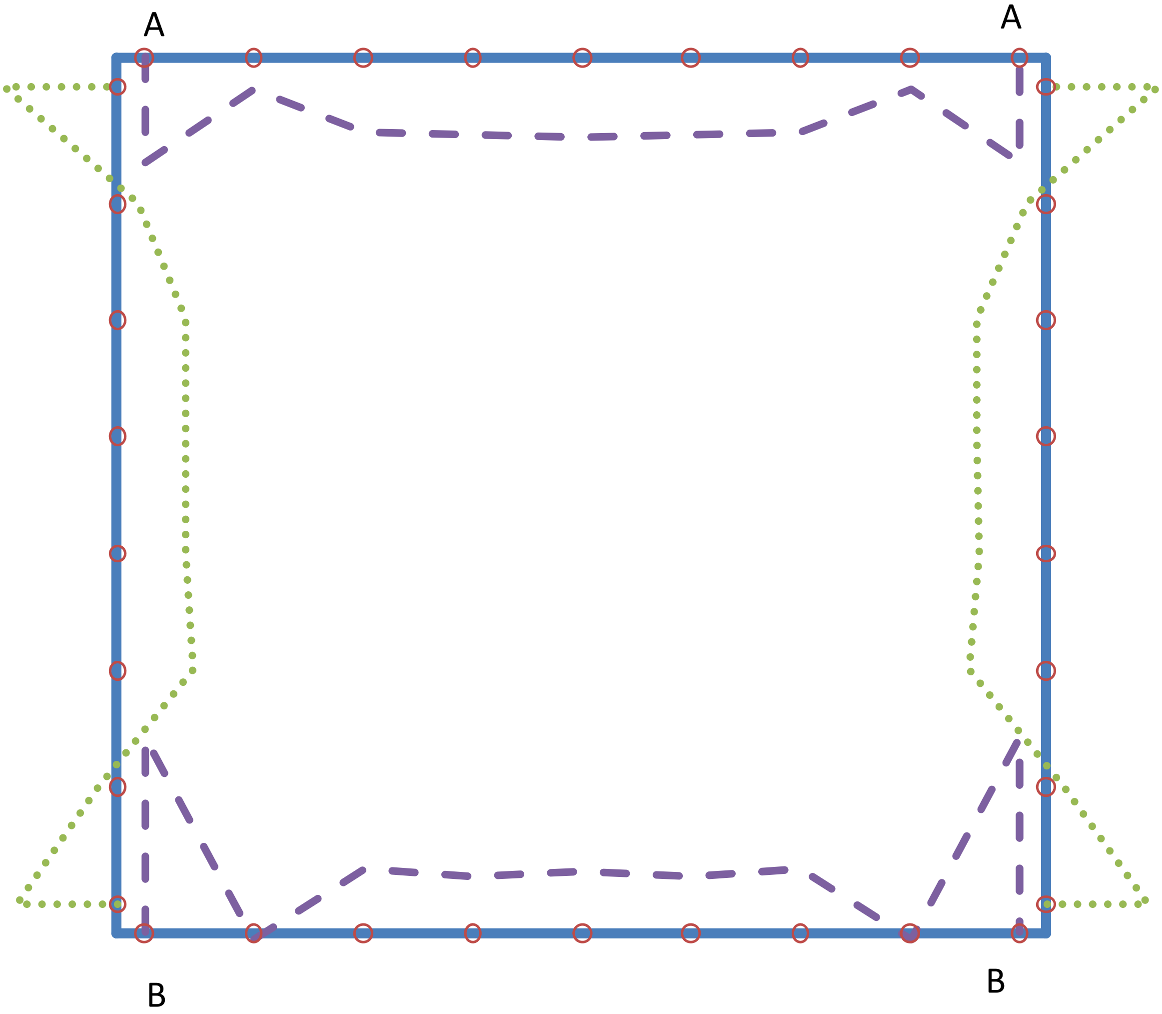


Figure 13. Staple shear force distribution around a window frame as calculated by Space Gass

The design resistance of a single staple is given by ø x R_{staple} where ø is the strength reduction factor and R_{staple} is the characteristic strength. Section 2.5 of NZS 3603 (SNZ 1993) gives ø = 0.7 for this type of fastener. For a satisfactory design, the design resistance must be greater or equal to the design action.

$$\text{Thus, } ø \times R_{staple} \geq K \times W_{ULS} \times L_W \times H_W / n \text{ .... (9)}$$

The maximum staple shear forces will vary with window area and aspect ratio and member stiffnesses. Non-linear member behaviour and partial pull-out of the most critically loaded staples are likely to reduce the peak staple forces. However, for the purposes of the following analysis in this report the maximum staple force, F_{max}, has been taken as K x F_{mean} with K being set to the following values: 1, 2 and 4 to cover the expected range.

For staples placed at 200 mm centres, $n \approx 2(L_W \times H_W)/0.2 + 4 = 10(L_W \times H_W)+4$

Thus, $0.7 \times R_{staple} \geq K \times W_u \times L_W \times H_W / (10(L_W \times H_W)+4)$ ... (10)

Based on Eqn (10), the limits for L_W and H_W are plotted for different values of K in Figure 14 to Figure 16. Assumptions used in deriving these graphs were:

1. W_{ULS} = 1.93 kPa (very high wind from Table 1).
2. R_{staple} values for coated staples in pine and Dynaboard reveals and stainless steel staples in Dynaboard reveals were taken from Table 2.
3. Staple spacing = 200 mm starting at 50 mm from a corner.
4. The sill trimmer and lintel connection strength to the trimming stud is adequate to transfer the loads.

A graph of window area versus window height is shown in Figure 17. It can be seen that limits for L_W and H_W are critically dependent on the value of K assumed. The limits for K = 1 impose little restrictions on normal usage, whereas that for K = 4 would be very onerous especially for Radiata pine reveals with coated staples.

This limited study indicates that the current staple fixings will be overloaded in large windows in very high wind zones when experiencing design level winds. Although such high differential pressures will rarely occur it is recommended that staple spacing be closed up in such design situations. It is also recommended that a more detailed investigation be performed to more accurately study the problem. However, as an interim measure it is recommended that coated staple fixing centres be a maximum of 100 mm for pine reveals in very high wind zones when the glass area exceeds 1.5 m^2 and 4 m^2 for Dynaboard reveals. These areas can be increased to 2 m^2 and 5 m^2 respectively if stainless steel staples are used.

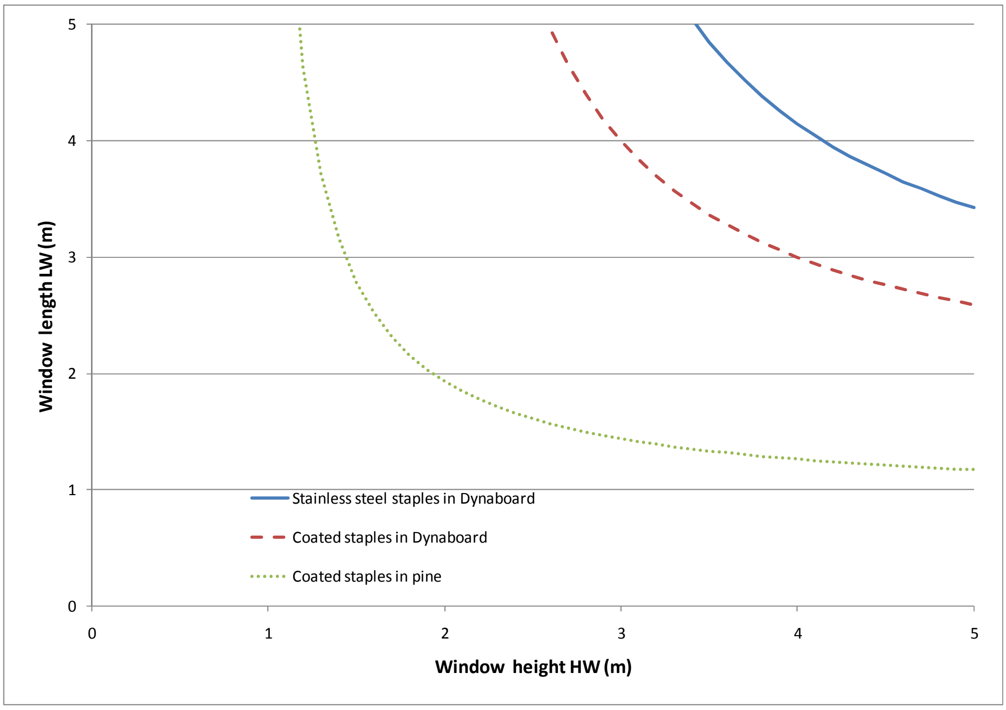


Figure 14. Window length and width limitation based on staple strength assuming K = 1

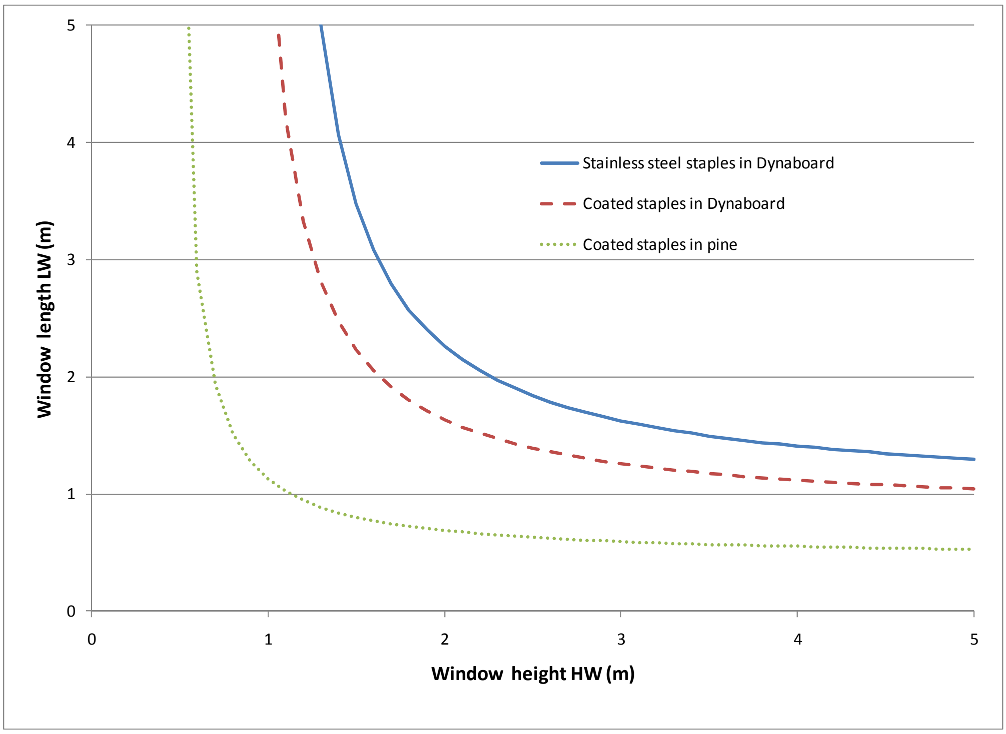


Figure 15. Window length and width limitation based on staple strength assuming K = 2

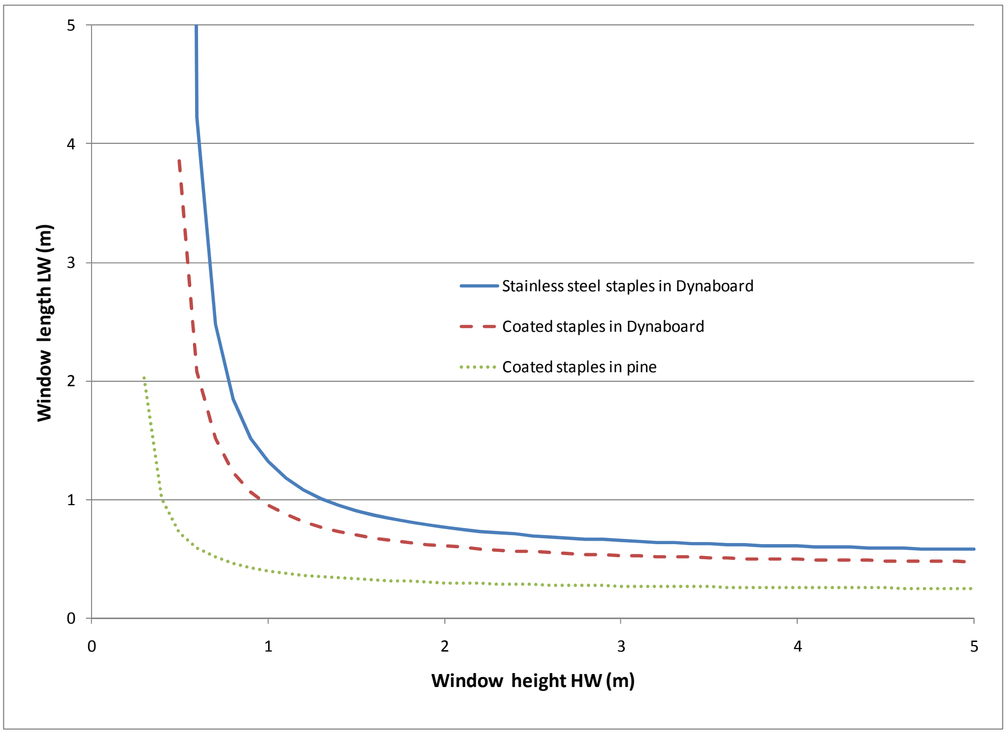


Figure 16. Window length and width limitation based on staple strength assuming K = 4

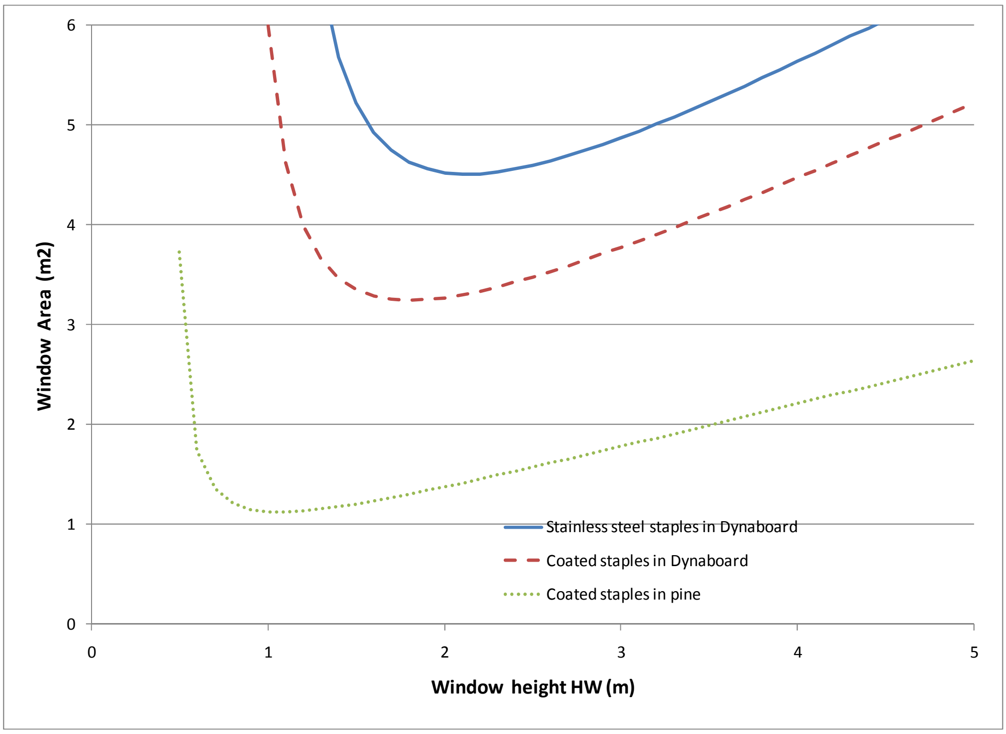


Figure 17. Window area limitation based on staple strength assuming K = 2

3.4.5 Summary of findings in Section 3

The analysis in Section 3.3.3 showed that the test pressures used in the window prototype tests to NZS 4211 are too low by a factor of almost 2.0. It is recognised that it is important that the test pressures are not too conservative. However, it is recommended that in any revision of NZS 4211 the committee revisit the required test pressures.

The prototype test in NZS 4211 does not test the connection between window and adjacent structure and this report examines this connection based on a single full-scale test and a series of elemental tests, as summarised below.

No damage was observed in a single face-load pressure test to 4 kPa on a 1600 mm wide by 1200 mm high window. The reveals were nailed to the trimming studs (with a gap between the two of approximately 7 mm) with a single 75 x 3.15 mm galvanised steel jolt-head nails at 150 mm from corners and thereafter at 450 mm centres. The aluminium window frame extrusion was stapled to the reveal with stainless steel staples positioned at 50 mm from window corners and then at 200 mm centres.

Based on elemental tests, the design shear strength for the nailed connection between reveal and window trimmers was determined. It was concluded that the fixing strength was adequate if pairs of nails were used at 450 mm centres, provided this is reduced to 300 mm centres in high wind zones for windows with area greater than 6 m^2.

Based on elemental tests, the design shear strength for the stapled connection between window frame and reveal was determined. Based on this and the results of a finite element analysis using 200 mm staple spacing, it is concluded that the staple connection may be overstressed in a house with large windows located in a very high wind zone when subjected to a design level windstorm. Although such high winds will rarely occur it is recommended that staple spacing be closed up in such design situations. It is also recommended that a more detailed investigation be performed to more accurately study the problem. However, as an interim measure it is recommended that coated staple fixing centres be a maximum of 100 mm for pine reveals in very high wind zones when the glass area exceeds 1.5 m^2 and 4 m^2 for Dynaboard reveals. These areas can be increased to 2 m^2 and 5 m^2 respectively if stainless steel staples are used.

4. SUPPORT OF WINDOW SELF-WEIGHT

4.1 Background

If windows where the glazing line is at an eccentricity to the framing are not adequately supported they will sag or even fail. The sagging may open up the frame corner mitre joints and/or the mullion connections, which may result in leaks well inside the framing line. A wall cavity will not help.

Many figures in E2/AS1 (DBH 2005) relate to window installation, but these do not show window support brackets, and nor do they require that they are an essential part of the window installation. There is a Note 3 attached to all these drawings containing the words: "*Where support brackets are required by the window manufacturer to carry the frame and glazing loads they must be supplied as an integral part of the window installation and installed to the window manufacturer's recommendations*". This has left window manufacturers confused as to what is needed.

WANZ developed a WANZ bar that was expected to be effective in transferring the load. However, this was expensive and has only being used in a small proportion of cases with builders generally "making do" with ad-hoc carpentry solutions. WANZ have recently produced a lighter cheaper bar and Section 4.2 discusses tests on this new WANZ bar.

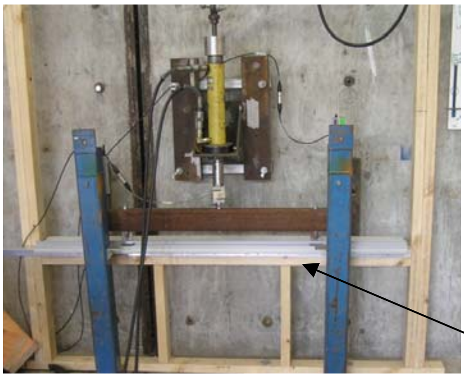
4.2 BRANZ vertical load tests on the new WANZ window support system

4.2.1 Introduction

Three tests were performed using a set-up shown in Figure 18, where eccentric axial load to simulate glazing weight was applied to a window frame supported by the new WANZ bar. Equal load was applied at window pane ¼ and ¾ span locations as this is where the window is supported on rubber glazing blocks in practice.

The test only used the portion of the aluminium window frame along the sill as shown in Figure 18. Had it been used around an entire window perimeter, some stiffening to the applied load may have been provided by the rest of the window frame depending on the rigidity of the joint between vertical and horizontal frame members. However, as this is a function of window frame type and window opening width, it was decided to omit this from the test to make the results more general.

The glazing weight was simulated by the load applied by the jack as shown in Figure 19 and Figure 20.



Window frame only used along sill~~.~~

Figure 18. Overall view of set-up

Figure 19. Close-up view of the loading system

4.2.2 Construction of test specimens

The framing consisted of 90 x 45 MSG 8 radiata pine timber in a typical arrangement for a 1.755 m wide window opening in a New Zealand house and is similar to Figure 8.5 of NZS 3604. The bottom plate was bolted to the laboratory strong floor and the top plate was rigidly tied back to the laboratory strong wall. There were two trimming studs on each side of the opening and two jack studs beneath the sill at 600 mm centres. Members were nailed together with two 90 x 3.15 power-driven Paslode nails as is current practice.

The sill trimmer also had a 90 x 45 mm cross-section and was fixed to the trimmer studs with 90 x 3.15 power-driven Paslode nails at each end as noted above. For wider window openings Table 8.15 of NZS 3604 stipulates larger sill timber sections. Table 8.19 requires three end-driven, power-driven nails to connect each end of the sill trimmer to the trimming stud for lengths up to 2.4 m and five nails for lengths not exceeding 3.6 m.

A 90 x 45 mm dummy sill section was screwed to the top of the sill trimmer as shown in Figure 20 and Figure 21. This was purely a passenger in the tests as it was not directly connected to the trimming studs i.e. the dummy sill section did not enhance the torque resistance of the construction for the eccentric loading imposed. The window joinery was attached to the dummy sill section, and so when this section was unscrewed from the sill trimmer either the window joinery or the sill trimmer could be separately replaced without affecting the other.

In the set-up for Test 1, the screws fixing the WANZ bar (which had been installed by a trade professional) were actually placed at an angle to the horizontal and partially protruded through the bottom of the dummy sill section. This was rectified at a few locations as BRANZ wished to move some screws. The screws were placed horizontally in Tests 2 and 3 as drawn in Figure 20.

A view of the assembled frame and WANZ bar is shown in Figure 22. A cross-sectional drawing through the sill showing the location of applied load and the critical dimensions and components is given in Figure 20. This shows the load being directly applied to the glazing setting blocks in a similar manner to which the glass self-weight would load the setting blocks in practice. The WANZ support bar is shown shaded black. The white sill packers (used to accurately locate the WANZ support bar) and the window support blocks (used at glazing setting block locations) are shown hatched in this drawing.

They can also be seen in the photographs of Figure 23 to Figure 25. The sill packers clip into the WANZ bar during installation. The window support blocks are used to pack between the window frame and the WANZ support bar so that the window weight is immediately resisted by the bar before any significant displacement of the window frame occurs. The relative positions of these components in an elevation view are shown diagrammatically in Figure 21.

A photograph of the window joinery being attached to the dummy sill section is shown in Figure 19 with a gap of 65 mm being used between face of the dummy sill and the inside face of the window frame down-stand as drawn in Figure 20 and Figure 22.

The external edge of the window frame was stapled to the dummy sill section at 50 mm from the ends and thereafter at 350 mm centres.

In Test 1 and 2, the loading was performed on new window frame, WANZ bar, reveal, packers, blocks and screws. Test 3 used the window joinery of Test 2 and only replaced the screws (which were all used at different locations from Test 2 as detailed below). New jack studs and sill trimmers were used in all tests.

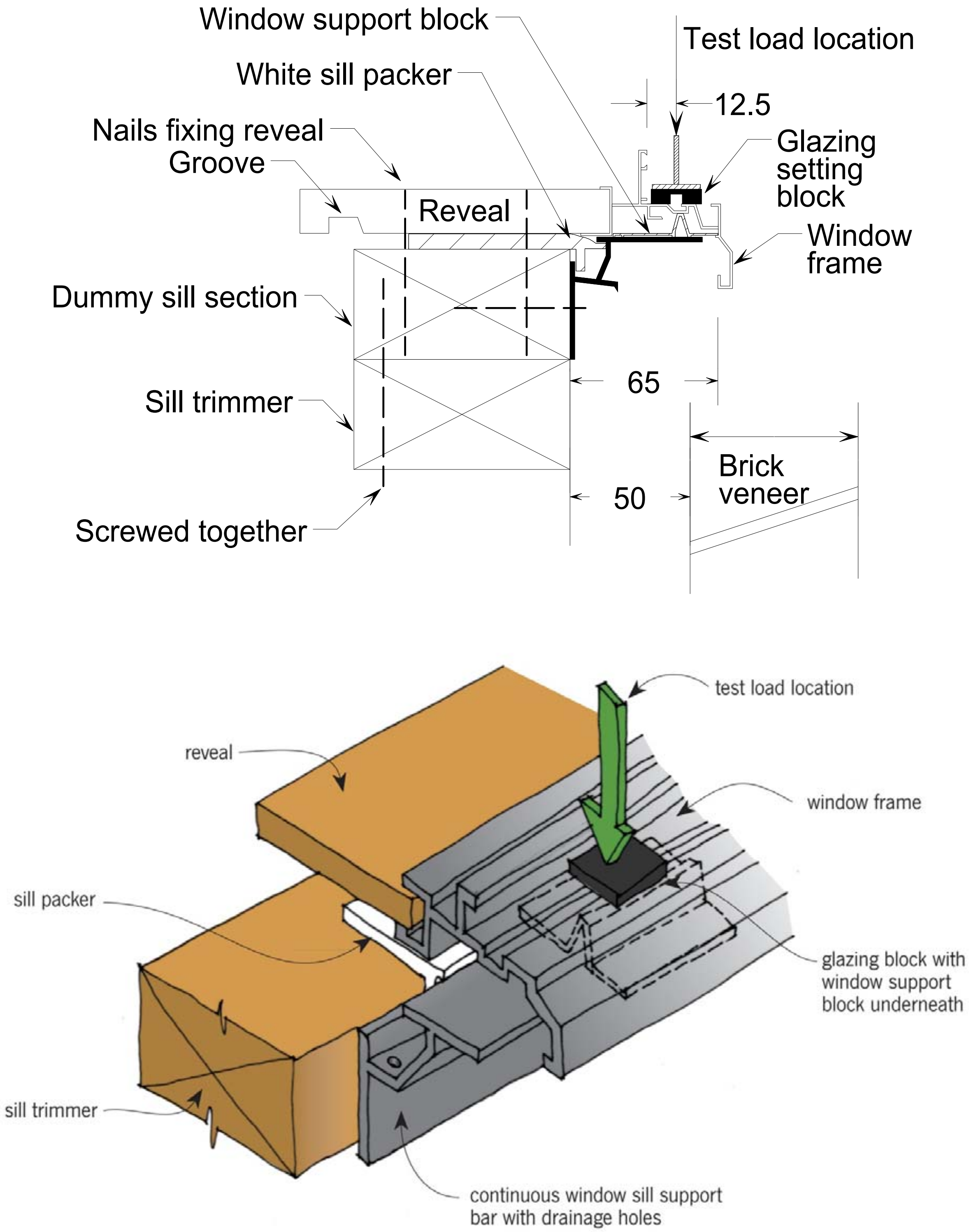


Figure 20. Cross-sectional view of window sill showing dimensions

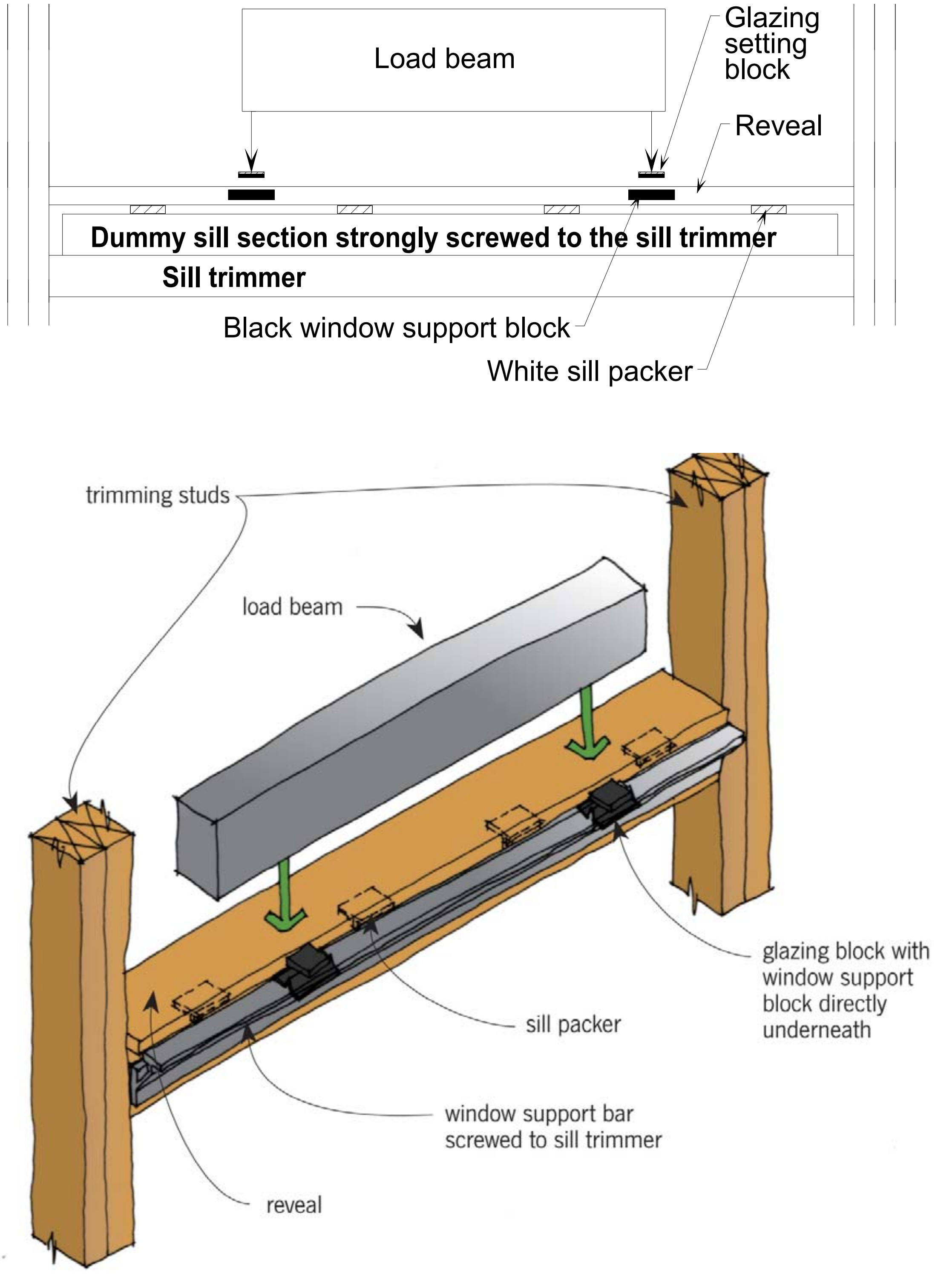


Figure 21. Diagrammatic elevation showing loading component positions

Figure 22. Photograph taken during installation of joinery to the dummy sill

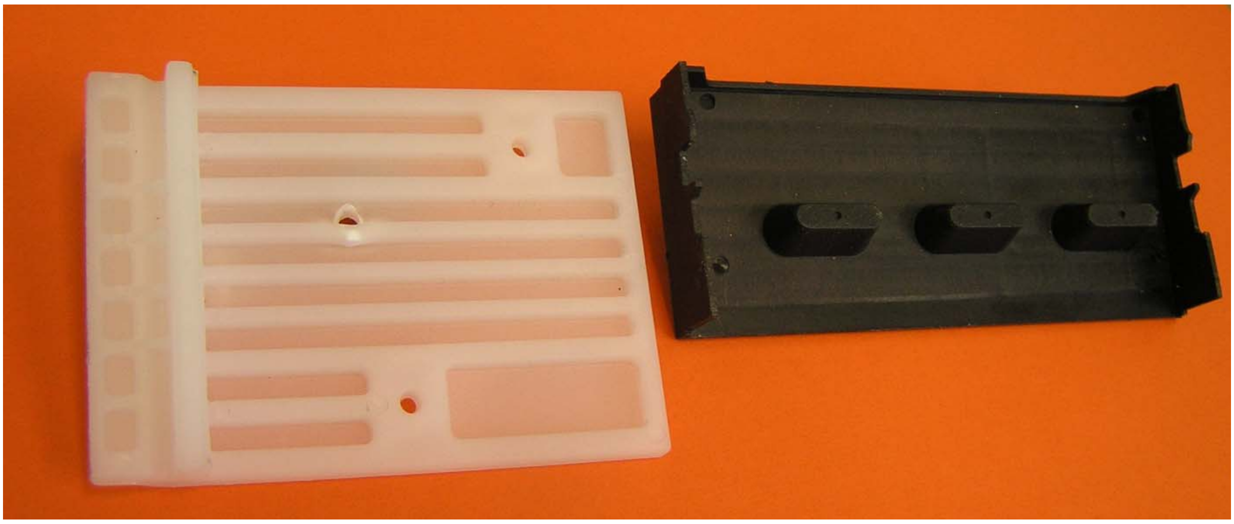


Figure 23. Sill packer (white) and window support block (black)

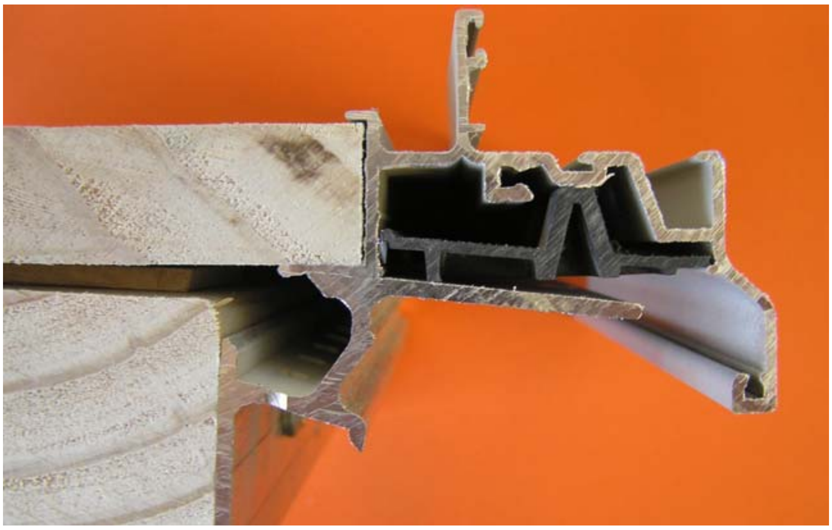


Figure 24. Window support block (black) in as-used position

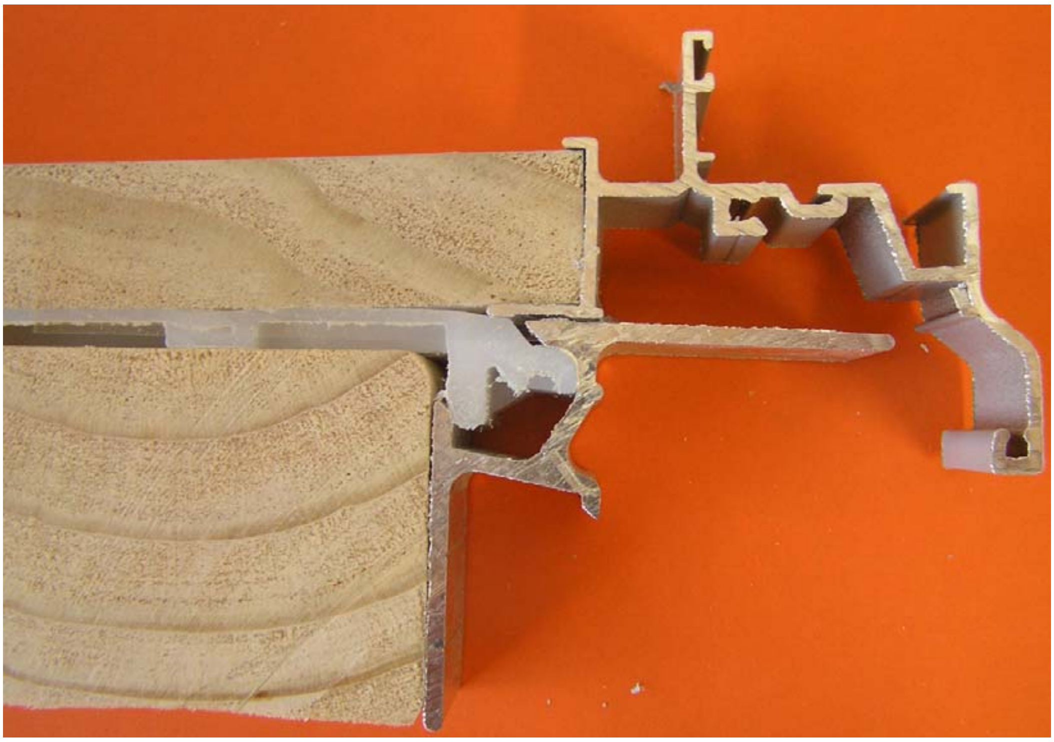


Figure 25. Sill packer (white) in as-used position

(a) Construction details common to all three tests were:

- The black windows support blocks were placed directly below the black glazing setting block located at window pane ¼ and ¾ span points i.e. 440 mm from the ends of the window opening as shown in Figure 20 and Figure 21. These are subsequently referred to as the “load locations”.
- Two 75 x 3.15 mm galvanised jolt-head nails were used to fasten the reveal to the dummy sill section at each white sill packer as shown in Figure 20 and Figure 21. These packers were placed at 450 mm centres with the first packer located at 215 mm from the window corner. This resulted in the two nearest packers to the load location being equal distance (225 mm) from the load locations to give the worst case loading.
- The WANZ bar was fixed to the dummy sill section using stainless steel screws placed through the top layer of holes in the WANZ bar. These were 21 mm above the bottom of the WANZ bar. No screws were used in the bottom layer of holes which were approximately 10 mm above the bottom of the WANZ bar. The total length of the screws was 53 mm (shank length = 50 mm) and they had a 9.3 mm diameter head (Figure 26). The screws were threaded for their full length and had a fine thread (6 threads/cm) intended for metal rather than the coarse thread used for timber. The outside diameter of the thread was 4.75 mm.
- The screw location fixing the WANZ bar to the dummy sill section varied in each test as shown in Figure 28.

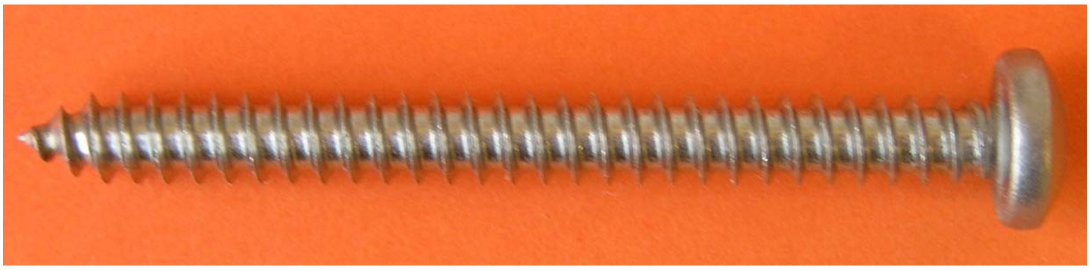


Figure 26. Screws used to fix the WANZ bar

Figure 27. Pairs of screws at load location used in Test 1 (note the presence of the black window support block)

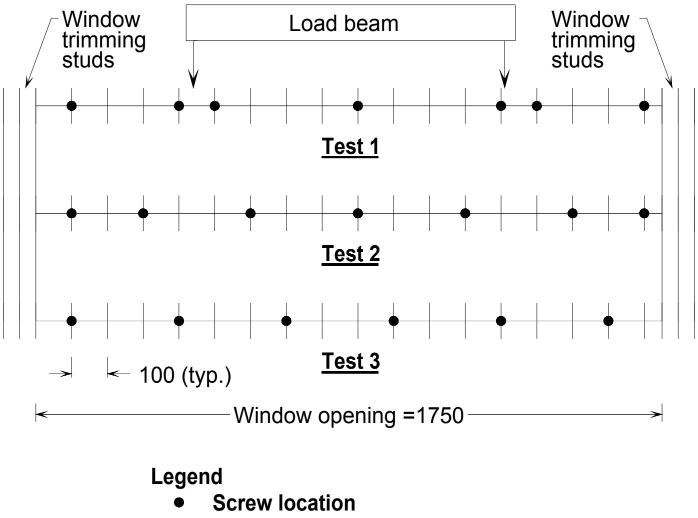


Figure 28. Screw locations

Figure 29. System to apply load onto steel plate covering the glazing setting block

(b) Construction details which varied between the three tests were:

Test 1 construction

- Pairs of screws (spaced 100 mm apart) fixed the WANZ bar to the dummy sill section directly below both load locations as shown in Figure 27. Elsewhere these screws were generally spaced 300 mm apart.
- The closest trimming stud to the window opening was fixed to the sill trimmer with two skew power-driven nails (one on each trimmer edge). This varies from the NZS 3604 fixing (used in Test 2 and 3), but was used for Test 1 as this construction is moderately common and was considered to likely represent the worst case.

Test 2 construction

- Single screws fixed the WANZ bar to the dummy sill section at approximately 150 mm either side of the load locations. Elsewhere screw spacing was approximately 300 mm. This was considered to be the worst case for failure of the WANZ bar.
- The closest trimming stud to the window opening was fixed to the sill trimmer with two power-driven nails through the face of the closest trimmer into the end of the sill.

Test 3 construction

This construction was designed to produce the greatest load on a screw used to fix the WANZ bar. The critical screws were the two which were below the load points.

- Single screws fixed the WANZ bar, generally at 300 mm centres, but starting directly below the load locations. This was considered to be the worst case for pull-out failure of the screw.
- "L-shaped" 25 mm wide straps were used to fix the sill trimmer to the jack studs, with three nails fixing the strap to the top of the sill trimmer (one side of the "L") and six nails fixing the strap to the inside face of the jack studs (the other side of the "L").
- Jack studs, also strapped, were added at the ends of the opening.
- The closest trimmer to the window opening was fixed to the sill with two power-driven nails through the face of the closest trimmer into the end of the sill.

4.2.3 Loading system

A vertical force was applied to a load beam shown in Figure 19. The force was measured with a load cell calibrated to International Standard EN ISO 7500-1 for Grade 1 accuracy. A 4 mm wide steel plate was fixed in a vertical orientation to the base of the beam at each specimen load point and was used to apply a vertical load to the mid-width of the glazing setting blocks as shown in Figure 20 and Figure 29. This is considered to simulate the loading from the weight of double glazing on the setting blocks. (Note that a 20 mm wide by 2 mm thick steel flat plate?? was used between the load steel plates and the glazing setting blocks to help spread the load as shown in Figure 29.)

4.2.4 Test results

A plot of the applied load versus displacement of the load beam in Test 1 and Test 2 is shown in Figure 30 and Figure 31 respectively. (Note that 1 kN = 102 kg.) The load beam displacement shown is the average from gauges at each end of the load beam and is expected to be similar to the glass displacement had it been located on the glazing setting blocks. In each case the test was terminated when the load deflection curve had flattened out. At this stage the rotation of the window frame had become large and the loading system shown in Figure 34 was starting to become unstable.

At completion of the first two tests it was noted that:

1. The reveal had partially separated from the window frame at the inside edge as shown in Figure 35 but remained firmly stapled at the outside edge.
2. In Test 1 the sill trimmer had twisted (Figure 37 and Figure 40) resulting in a gap of approximately 12 mm between the jack studs and sill trimmer at their inside edge. This gap was measured directly in Test 2 (see Figure 38) at both ends of the sill trimmer and one interior jack stud. From these measurements it was concluded that the greatest sill trimmer twist relative to the framing was at the interior jack studs and created a gap of approximately 7 mm at test completion i.e. smaller than in Test 1. The gap was negligible at 6 kN load which implies that 6 kN is a lower limit for SLS.

3. In Test 3 the window frame had separated from the reveal on the right-hand side of the specimen at approximately 1.5 kN applied load. However, this did not happen on the left-hand side until approximately 4 kN. The times of these occurrences may have been influenced by the reuse of the window frame which had already been used in Test 2. The separation of the frame from the reveal at the end of the test is shown in Figure 42.

4. The load versus deflection graph for Test 3 is shown in Figure 33. The specimen was held for approximately 30 seconds at Point A shown on the graph during which it exhibited less than 1% load drop-off. It was held for 90 seconds at B and had 8% load drop-off and 15 minutes at C and had 18% load drop-off.
5. In all tests the screws had kept the vertical leg of the WANZ bar tight against the sill trimmer as shown in Figure 39 and the reveal did not lift from the dummy sill section i.e. the nails fixing them together held tight.

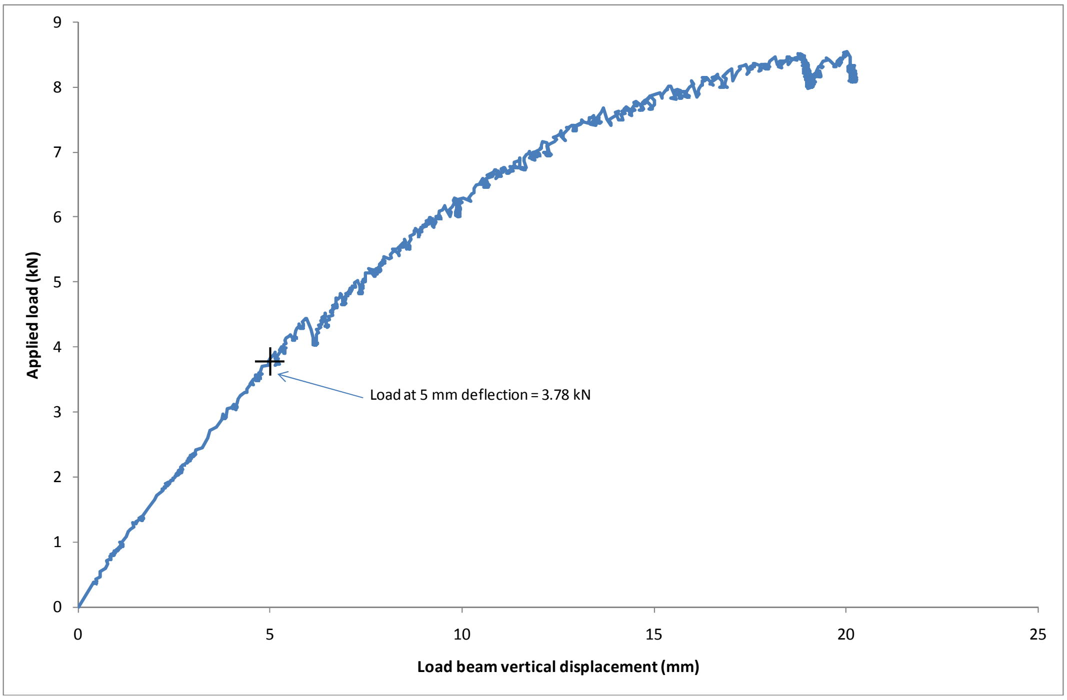


Figure 30. Load resisted in Test 1

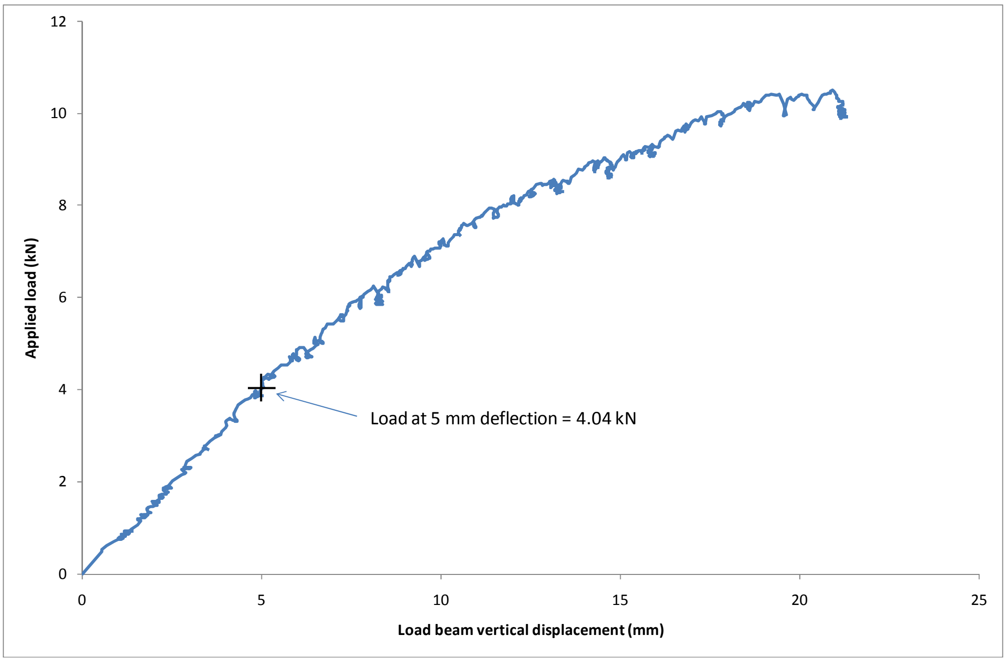


Figure 31. Load resisted in Test 2

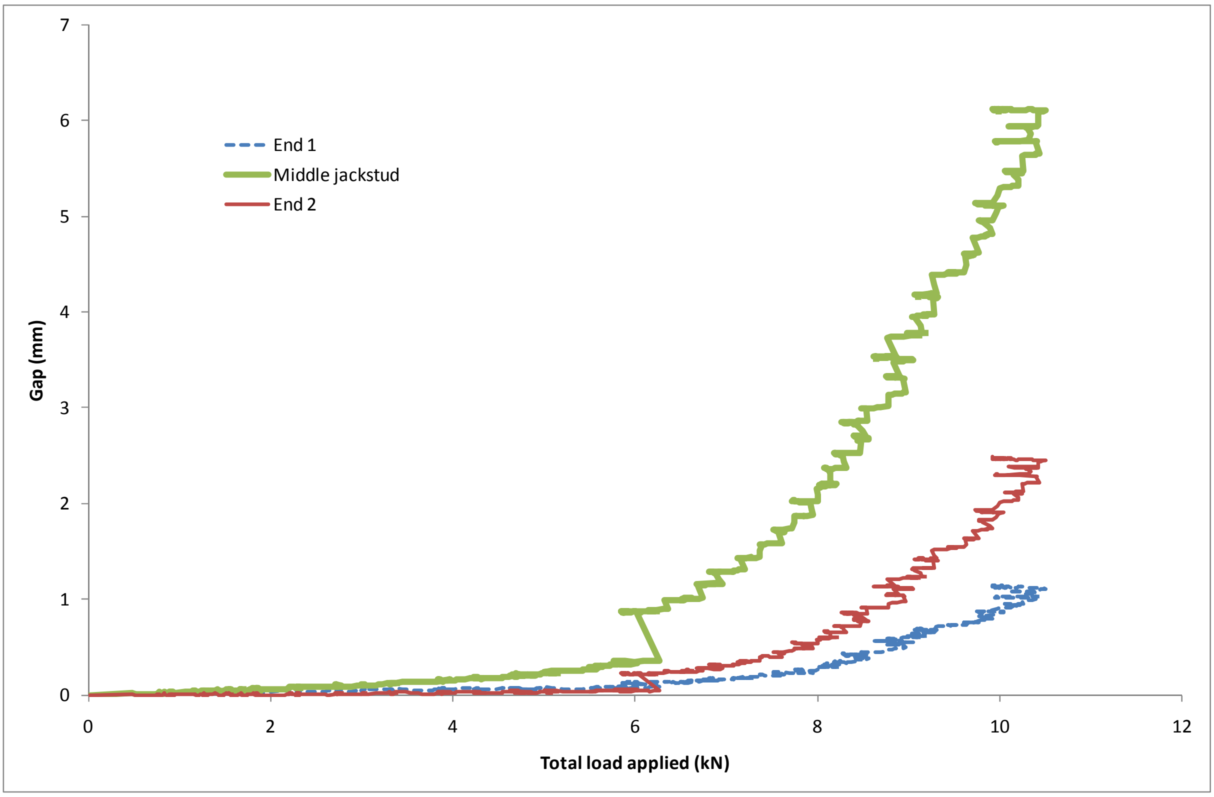


Figure 32. Upward movement of inside edge of sill trimmer

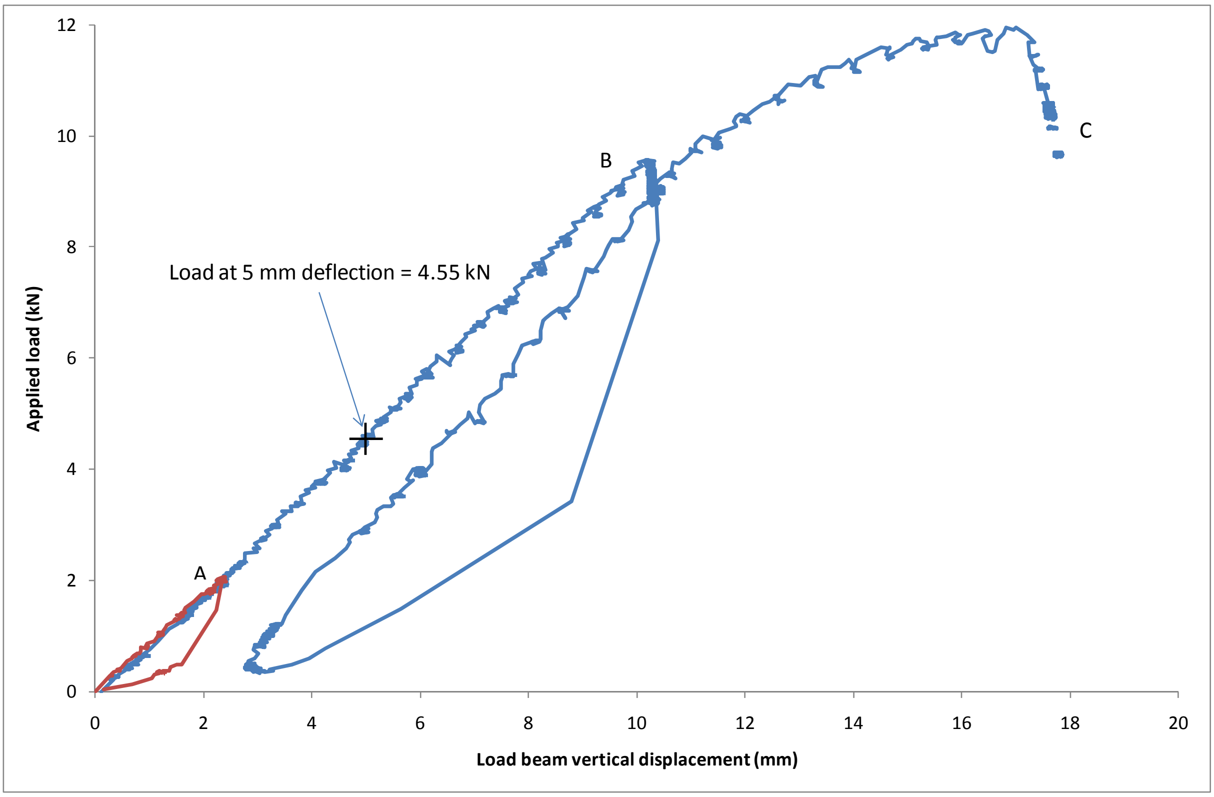


Figure 33. Load resisted in Test 3

Figure 34. Rotation of window frame and loading system

Figure 35. Distortion of the window frame and separation of frame and reveal at end of Test 1

Figure 36. Twist of sill trimmer in Test 1 (photograph taken after the dummy sill section had been removed)

Figure 37. Rotation of jack studs under sill trimmer in Test 1 at peak applied displacement

Figure 38. Test 2 deflection gauges and screw location

Figure 39. Screws fixing WANZ bar to the sill trimmer at test completion – no apparent pull-out

Figure 40. Test 2 frame off reveal and distortion observable at test completion

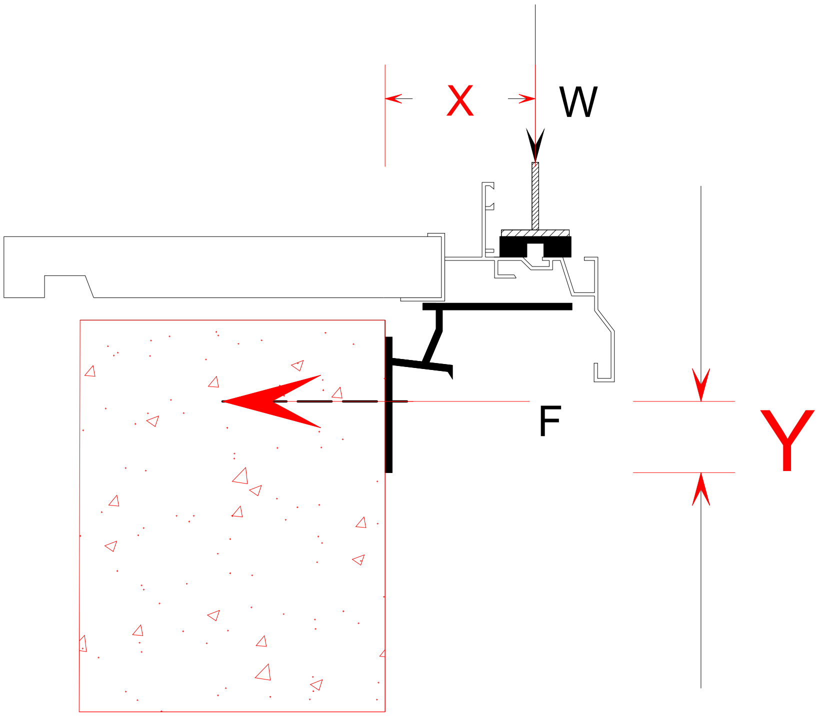


Figure 41. Cross-section through the base of a window where the WANZ bar is fixed to concrete, showing forces due to glazing self-weight

Figure 42. Cross-section at right-hand side of Test 3 at test completion

4.2.5 Acceptable window vertical deflection

If a window deflects too far various serviceability problems can occur (e.g. the mitre joints and mullion connections of a window frame may open sufficiently to allow moisture ingress to occur, the deflection may be visually apparent and unacceptable and window opening may be impeded.) The acceptable window vertical displacement is unknown. For the purposes of this report the author has assumed the maximum displacement is 5 mm. However, others using the maximum window weights so derived will need to verify that this displacement is acceptable or else choose/determine new displacement limits and calculate the window weight from this value using the method outlined herein.

In Tests 1, 2 and 3 the load resisted at 5 mm displacement was 3.78, 4.04 and 4.55 kN respectively.

4.2.6 Analysis of test results

This analysis is based on AS/NZS 1170.0:2002.

No pull-out or failure of the screws fixing the WANZ bar occurred in any test. The loading on the screws was highest in Test 3 as these had only a single screw directly under the load point and the maximum applied load in this test was greatest. Apart from the location of screw fixings Test 1 and Test 2 were identical. As the screw fixing strength was not critical, Tests 1 and 2 can be considered replicate test specimens. If a coefficient of variation of 15% is assumed then kt = 1.64 for two specimens from Table B1 of AS/NZS 1170.0:2002. However, this is dependent on WANZ removing the bottom row of holes as otherwise people will use these holes in preference and the strength would reduce and the coefficient of variation greatly increase. It is recognised that the coefficient of variation of 15% assumed above is purely an estimate by the writer, rather than being derived from replicate test specimens, and the result is very dependent of the value assumed.

(a) Serviceability limit state

The calculations below assume that a value of 3.78 kN (385 kg wt) is adopted as the SLS for the arrangement tested as the load deflection curve is effectively linear at this stage and the jack stud had not separated from the dummy sill section. WANZ will have to decide if the corresponding deflection at this stage (5 mm) is acceptable.

If 5 mm is considered to be acceptable, the design capacity is 385/1.64 = 235 kg wt. The serviceability action force from NZS 1170.0 is purely the gravity load. Thus, the maximum weight of glass is 285 kg wt. Note that a 3 m long window of height 2.2 m and total glazing thickness of 12 mm only weighs 2500 x 3 x 2.2 x 0.012 = 198 kg and thus the deflections on-site are likely to be significantly less than 5 mm.

(b) Ultimate limit state

The minimum strength from the two tests was from Test 1 and was 8.4 kN. The ultimate action force from NZS 1170.0 is 1.35 times the gravity load. Thus, the maximum weight of glass is 8.4 x 102/(1.64 x 1.35) = 387 kg wt. Hence, the SLS governs.

4.2.7 Fixing to concrete

The WANZ bar will sometimes need to be fixed to concrete as shown in Figure 41. In this case an axial force due to the window weight of W at an eccentricity of X will need to be resisted by a concrete anchor with force F_{Load} which can be calculated from the distance Y from the bottom of the WANZ bar by: $F_{Load} = WX/Y$. The design level anchor strength must be $\geq 1.35\ F_{Load}$ where 1.35 is the load factor from NZS 1170.0.

A search on Google shows that there are many systems available that could be used to fix the WANZ bar to concrete. Less data is available on the characteristic pull-out strength of these fasteners for small edge distances. Increasing Y and reducing fastener spacing will increase the fixing strength. Note that the concrete compressive strength for domestic construction is specified in NZS 3604 to be 17.5 MPa and this value should be used in any calculations or tests.

This problem is outside the scope of this study. The writer recommends that WANZ selects one or more fasteners suitable for use on-site and determine the characteristic fastener pull-out strength for the appropriate edge distance by test or from the manufacturer's literature. Let's say this is found to be = F_{conc}. The design strength = $\o F_{conc}$. Thus, $\o F_{conc} \geq 1.35\ F_{load} = 1.35\ WX/Y$. WANZ would then stipulate the spacing and type of fastener to use and the type of WANZ bar.

4.2.8 Conclusions

Provided only the top rows of holes are used on the WANZ bar then the screws and WANZ bar provided, as described in this report, will be adequately strong and not affect the system strength. Care must be taken to put the screws in horizontally.

The critical deformations were:

- The sill trimmer rotating on the top of the jack studs. Test 3 showed this could be remedied by using jack studs at both ends of the sill trimmer and by using steel

straps at the top of the jack studs. However, in the testing done herein, gaps between sill trimmer and studs were small for total window weights less than 6 kN (612 kg).
- The window frame separating from the reveal.
- The vertical deflection of the window frame which could result in leaks at mitre joints etc. This was mainly due to twist (rotation) of the WANZ bar. An acceptable displacement is unknown but the calculations above indicate that it is the critical parameter limiting window weight. Extending the leg of the WANZ bar by say 30 mm while keeping the same screw hole location may reduce this twist.

(a) Fixing to timber

Provided WANZ:

1. Removes the bottom row of holes in the new WANZ bar.
2. Consider that the 5 mm deflection noted above is an acceptable SLS which will not result in problems on-site.

Then the maximum weight of a window pane (for the eccentricity tested) is 235 kg weight provided it:

1. is supported at quarter points as tested
2. uses the screws and either of the screw layouts of Test 1 and Test 2
3. uses a continuous WANZ bar and not "shorts".

For very heavy eccentric windows (without defining these variables at this stage) it is recommended that the straps and extra jack studs of Test 3 should be used to prevent the sill trimmer separating from the jack studs.

(b) Fixing to concrete

This has been discussed above, but no solution was determined.

5. CONCLUSIONS

Conclusions regarding window fixings for face-load pressures are given in Section 3.4.5.

Conclusions regarding window supports to carry the self-weight of a window at eccentricity is given in Section 4.2.8.

6. REFERENCES

BRANZ Ltd. 1999. 'Evaluation Method No 1 (1999)'. Structural Joints – Strength and Stiffness Evaluation'. *EM No. 1.* BRANZ Ltd, Judgeford, New Zealand.

Department of Building Housing. 2005. *Compliance Document for the New Zealand Building Code: Acceptable Solution E2/AS1 for Clause E2*. DBH, Wellington, New Zealand.

Department of Building Housing. 2007. *Compliance Document for the New Zealand Building Code, Clause H1, Energy Efficiency – Third Edition*. DBH, Wellington, New Zealand.

Leitch C, Ginger J, Harper B, Kim P, Jayasinghe N and Somerville L. 2009. *Investigation of Performance of Housing in Brisbane Following Storms on 16 and 19 November 2008*. Report TR55, April 2009, Cyclone testing station, James Cook University, Townsville.

Standards New Zealand. 1992. NZS 4203:1992. *General structural design and design loadings for buildings.* SNZ, Wellington, New Zealand.

Standards New Zealand. 1993. NZS 3603:1993. *Timber structures standard.* SNZ, Wellington, New Zealand.

Standards New Zealand. 1999. NZS 3604 *Timber framed buildings.* SNZ, Wellington, New Zealand.

Standards New Zealand. 2002a. AS/NZS 1170.0 *Structural design actions. Part 0: General principles.* SNZ, Wellington, New Zealand.

Standards New Zealand. 2002b. AS/NZS 1170.2 *Structural design actions. Part 2: Wind actions.* SNZ, Wellington, New Zealand.

Standards New Zealand. 2008a. AS/NZS 4284 *Testing of building facades.* SNZ, Wellington, New Zealand.

Standards New Zealand. 2008b. NZS 4211 *Specification for performance of windows.* SNZ, Wellington, New Zealand.

Standards New Zealand. 2008c. NZS 4233 *Glazing in buildings. Part 1: Glass selection and glazing.* SNZ, Wellington, New Zealand.

Standards New Zealand. 2008d. NZS 4233 *Glazing in buildings. Part 4: Wind, dead, snow and live actions.* SNZ, Wellington, New Zealand.

Yolland JR. 2007a. *Commentary on Future Residential Window Test Pressures*. Commentary to Windows Association of New Zealand (March and December 2007).

Yolland JR. 2007b. *Report 07/33: Evaluation of Maximum Load Capacity of Alternative Staple Fastenings for Reveals of Aluminium Framed Windows and Doors*. Report to Windows Association of New Zealand (December 2007).