BRANZ

STUDY REPORT

No. 187 (2008)

Retrofitting of Houses to Resist Extreme Wind Events

G.J. Beattie

FUNDED BY THE BUILDING RESEARCH LEVY
BUILDING RESEARCH

The work reported here was funded by Building Research Levy.

ISSN: 1178-4938

Preface

This is a short report providing a background to the development of the wind loading provisions for light timber-framed (LTF) houses over the decades and indications of the likely deficiencies in houses constructed prior to the latest (1999) issue of the LTF standard, NZS 3604, with respect to their performance in extreme winds. Retrofit solutions are provided for the roof cladding and roof framing and costs have been estimated for retrofit solutions. Readers should note that houses that have been built to superseded standards are not required by law to undertake an upgrade to the structural system of their house unless that after an alteration there is a need to strengthen the house so that it will continue to comply with the structural provisions of the NZ Building Code to at least the same extent as before the alteration. This might occur, for example, if a house is relocated to a site which has a higher wind zone. In all cases, a building consent covering the alterations will be required and the new work will be required to satisfy the requirements of the NZ Building Code and its referenced building standards.

Acknowledgments

This work was funded by the Building Research Levy.

Note

This report is intended for engineers, builders, territorial authorities and home owners.

Retrofitting Houses to Resist Extreme Wind Events

BRANZ Study Report SR 187

G.J. Beattie

Abstract

The risk of damage to existing LTF buildings due to extreme winds is dependent both on the level of the wind event and on the quality of the construction. The non-specific design standard for LTF buildings, NZS 3604:1999, provides engineered requirements for fixing framing to resist wind events that have a probability of 1/500 of occurring over the lifetime of the building. Houses constructed to this standard are not expected to sustain significant damage in any extreme wind event up to the design load levels on which NZS 3604:1999 is based.

The majority of the New Zealand housing stock was constructed before 1999 to earlier versions of NZS 3604, or even earlier standards. Because of this, there is the potential for such houses to be damaged because the fixing requirements were not so well engineered. Furthermore, over the years the understanding of the wind flow across the country and around obstacles such as hills has meant that the design loading on structures has changed. For example, early versions of NZS 3604 made no allowance for hill shapes in the vicinity of a house and there is the potential for a house to have been designed for a Low wind area that is now categorised as a Very High wind zone. Such a building is not likely to have the fixings required to resist the greater wind pressures.

Evidence has shown that the parts of a house most damaged by extreme winds are the roof and its cladding. The loss of a roof can cause a domino effect with the consequent loss of walls, and it is therefore important to ensure that the roof is well secured.

This report provides a selection table for possible retrofit solutions for roof member connections based on the age of the house. Some knowledge of the derivation of the wind area and wind zone in accordance with NZS 3604 is required to be able to use the table. The solutions have been costed for individual houses and a range of likely cost is given.

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1. INTRODUCTION

The impetus for this report was derived from the observations made after the tornado events that occurred in the Taranaki region in July 2007. It seemed at the time that there may be a need to consider more than the normally occurring wind strengths in the design of structures in certain parts of New Zealand, these being the West Coast of the South Island and the North Island coast from Taranaki to Northland.

It was suggested by representatives of the Department of Building and Housing (DBH), who visited the areas of damage after the July events, that it would be unnecessary to consider designing buildings for tornado-type events (DBH 2007). However, it is acknowledged that the requirements for the securing of framing and cladding materials in LTF structures have increased over the years, as knowledge of wind forces and fastener strengths has also improved.

It was decided that it would be a useful exercise to quantify the likely deficiencies in houses built prior to the introduction of NZS 3604, and even during the development of that standard, and to develop retrofit solutions for these structures to match the expected wind loading demands placed on them. From this point of view, extreme winds are considered to be those that are the maximums expected for the particular wind zone in which the house is located.

2. WIND EFFECTS ON HOUSES

It is important to understand the wind flow over houses and the effects on the structure as a whole and the individual elements of the structure. In general terms, the house is subjected to a nett force that is made up of the individual force components on the various faces of the building. In extreme wind events, this force is not generally of importance, as long as the structure has been properly connected to its foundation. It is rare to see a whole structure, other than temporary structures such as worksite huts, completely displaced in an extreme wind event. The reason for this is that all the local forces used to design the individual element connections are unlikely to occur at once, because the applied wind is not regular and uniform.

More generally it is the local wind effects that cause damage to the house. For example, it is well known (and it is codified in building standards) that local increases in the basic pressures occur from time-to-time during the storm because of the way that the wind flows over the structure. An approximate depiction of the forces on the building under wind action is presented in Figure 1.

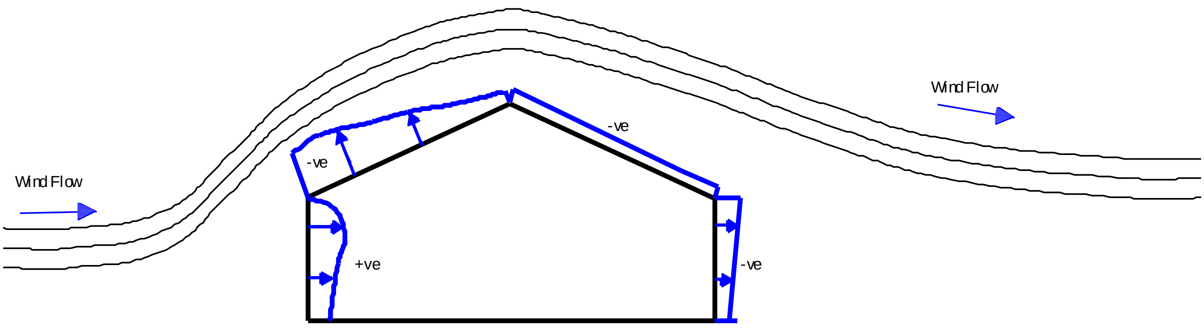

Figure 1. Wind flow over a building and consequent local pressure effects

It is the local effects that can cause the cladding materials to detach from the structure or sections of the structural system to uncouple. Such failures can have a devastating effect on the remaining structure because they can cause an alteration to the pressure distribution in the building to a situation not originally designed for. For example, loss of a window pane on the windward face can cause the internal space to be pressurised beyond that assumed in the design. The result may be failure of glazing on the leeward wall of the house or, at worst, loss of the roof structure. Similarly, loss of roof cladding can cause an over-pressurisation of the ceiling space (Figure 2), leading to the loss of further cladding, or perhaps the whole roof frame if it is not well attached to the walls.

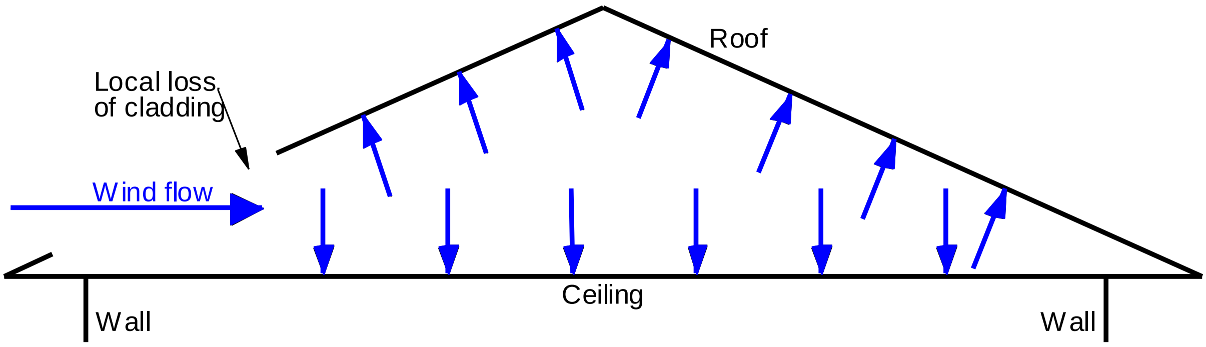

Figure 2. Pressurisation of roof space due to local loss of roof cladding

3. CLIMATE CHANGE CONSIDERATIONS

In a study such as this it is necessary to consider what likely changes may occur over the next few decades to the weather patterns over New Zealand. A report was produced for BRANZ by NIWA (NIWA 2006) in which it is stated that the expected extreme wind change is likely to be only 10% over the next 80 years. Therefore, it is not considered necessary to allow for increased wind loadings on structures in the short to medium term at least.

4. CLADDING SYSTEMS

4.1 Wall claddings

History has shown that wall claddings do not usually pull off the framing, even though they may be seriously damaged by impacting objects. The presence of the wall linings means that the differential pressure over the cladding is small.

Any sort of retrofitting procedures for older wall claddings are not considered necessary and have not been investigated in this report.

4.2 Windows

Windows have traditionally been timber framed, whereas most window frames are now made from aluminium extrusions. The author has no knowledge of losses of whole window frames in extreme wind events in New Zealand.

Glass could potentially fail under wind pressure during an extreme wind event. The selection of glass in windows is covered by NZS 4223.4 (SNZ 2000) and the manufacture of windows by NZS 4211:1985 (SNZ 1985). As long as the glass thickness has been correctly selected for the location of the building, the likelihood of it fracturing is small. The possibility of large picture window panes failing in an extreme wind event is greater than for smaller panes because the chance of being impacted by flying debris is greater (bigger target). This is not seen as a compelling enough reason to increase the glass thickness in such sized windows across the board, given the low number of occurrences of extreme wind events.

4.3 Roof claddings

The type of roof cladding present will have a significant bearing on the potential for damage in an extreme wind event. This is because the cladding may be heavy, thus able to resist the applied wind uplift through gravity forces, or it may be sufficiently porous to prevent a large pressure differential from developing across the surface, with consequent failure.

It is assumed that modern claddings are well enough fixed that retrofitting will not be necessary.

For older properties, the roof common cladding types used include:

- Corrugated galvanised steel sheets
- Pressed metal tiles/shingles
- Trough section galvanised steel
- Corrugated asbestos sheets
- Concrete and clay tiles
- Bituminous felt
- Mastic asphalt.

These are addressed in the following sections.

4.3.1 Corrugated galvanised steel sheets

This cladding system is by far the most common roof cladding on older structures. The common method of fixing the sheets to the purlins or sarking was with lead head nails. It was typical to fix the sheets with one nail every alternate crest of the profile near the eaves, ridge and gable, with the spacing reducing to every third crest in the body of the roof. Roofs clad before 1970 are not likely to have single sheets running from the eaves to the ridge. Over time, the passage of people over the roof during maintenance, such as painting, can cause the lead head to loosen on the nail head and sometimes the lead head will pop off the nail.

An older roof should first be inspected to determine the condition of the existing nails. Any nails that have lost their heads should be replaced. Corrugated galvanised steel claddings that have been fixed with screws and washers are likely to have a much greater resistance to loss of the cladding in high winds than nailed claddings because the screws have greater pull-out resistance. Retrofitting of these roofs will not be required. Roofs that are fixed with lead head nails that are in NZS 3604:1999 High and Very High wind zones can be improved at low cost by the addition of a new screw fixing on the crests between the existing nails, along the rows adjacent to the eaves, ridge and gable ends. Extra fixings are also recommended where sheet ends overlap. If it can be determined that the cladding is fixed through sarking boards rather than purlins, then the additional fixings should be placed slightly further up the slope of the roof so that they penetrate the adjacent sarking board rather than the same board. This will ensure that the uplift loads from the wind are spread over the two boards rather than being concentrated on one only. The same principle should be employed at the ridge, although in this case the new row of fixings will generally need to be slightly down the slope.

4.3.2 Pressed metal tiles/shingles

Pressed metal tiles are a proprietary item and therefore come in a number of shapes and sizes. The fixing method is also different between manufacturers.

Metal tiles are generally fixed to the tile batten through a lip on the bottom edge of the tile. The fixings (usually nails) pass through this lip and the turn-up at the top of the lower tile, penetrating the front edge of the tile batten. Hence, each tile is fastened directly to the timber frame at both the top and bottom edge. The fixings are not likely to fail because they are placed in shear rather than withdrawal under wind uplift pressures. The advantage with such tiles is that extra nails may be added at any time if it is considered necessary.

Metal shingles are often fixed at their top edge to the framing, and the next shingle up the roof is fitted over a formed upstand near the top of the lower tile to lock it into place. Hence, the fixing is hidden and each shingle is fixed to the framing only at its top edge. However, as long as the two shingles are properly interlocked, there is a low likelihood that a fixing failure will occur.

4.3.3 Trough section galvanised steel

This type of roof cladding is much less common on older houses (prior to 1970). It is generally run from the eave to the ridge in a single unjoined length. The fixing system for these roofs is completely hidden. Brackets are fixed to the purlins and then the roof cladding is “clipped” onto the brackets. Nothing can be done retrospectively to improve the resistance of this type of cladding to uplift from wind without the use of invasive methods. Having said this, the author is not aware of many failures of these roof systems under extreme wind.

4.3.4 Corrugated asbestos sheets

This is an old roofing system (not used since 1983) that can be very brittle (not to mention the asbestos fibre risk when it is disturbed). Such systems are generally screw fixed with steel and rubber washers beneath the heads. While susceptible to damage from impacting objects, the weight of the sheets assists in their resistance to wind uplift and additional fixing of the sheets will generally not be necessary in any of the NZS 3604 **wind zones**.

4.3.5 Concrete and clay tiles

The sheer weight of these systems means that there is little likelihood that the tiles will be dislodged in an extreme wind event. Coupled with this, air can flow between the tiles so that there is less pressure difference between the outside and the ceiling space. No upgrading of concrete or clay tile roofs is expected to resist extreme wind events. Some tiles have a lug on their underside with a hole to allow the tile to be wired to the battens. Over time, this (often thin) wire can corrode (if it has ever been installed) and replacing the wire will help ensure that the tiles are not lost from the roof in either an earthquake or extreme wind.

4.3.6 Bituminous felt and mastic asphalt

Both of these materials are laid over and adhered to a flat substrate such as plywood. The critical element is the fixing of the plywood and this is hidden from view in the completed roof. A properly maintained roof should not have allowed moisture to penetrate over its life, which could possibly cause corrosion of the substrate fixings. As long as the waterproof membrane is in good condition (i.e. no loose flapping ends), there is no opportunity for the wind to get underneath the membrane and roofing uplift problems are not envisaged.

5. CONSIDERATION OF BUILDING STANDARDS REQUIREMENTS

The construction of LTF buildings has been controlled to some degree since 1944. The original model bylaw was published in December 1935 as NZS 95 (NZSI 1935). However, the preface to the bylaw stated that “Sections I-X now presented, do not cover welded structures nor timber buildings". Indeed it took until 1944 before Part IX Light Timber Construction was published. Apparently, the requirements around wind resistance were mainly qualitative rather than quantitative.

In 1964, NZS 95 was replaced with NZS 1900 (SANZ 1964). Once again, the requirements for roof coverings were largely qualitative, the standard stating "provision shall be made to prevent fabric roofing being lifted by wind". Asbestos cement roofing was required to be laid and fixed in accordance with NZS 282 Asbestos cement sheets.

The situation was different for timber roof framing. While purlins were only required to be "securely fastened", rafters had to be double skew nailed. If they were Radiata Pine or Douglas Fir, then additional wires or strapping was required at 4 ft 6 in. maximum centres along the plate (effectively every rafter because these were spaced at 3 ft centres) and this was required to be continued onto end nailed studs.

5.1 Uplift pressures calculated from modern standards

Shelton (2007) presented the basic wind pressures calculated from the wind speeds associated with the four NZS 3604:1999 (SNZ 1999) wind zones. These are tabulated in Table 1.

It is necessary to adjust the basic wind pressures to take account of the flow of the roof surface and the proximity to the edges of the roof. To adjust for the flow effect, the basic pressures for rafter and truss design must be multiplied by a pressure coefficient, C_p, of 1.1. Purlins that are in the peripheral areas of a roof are subjected to even greater uplift pressures and a further local coefficient multiplier, K_l, of 1.5, must be applied. These adjusted pressures are also presented in Table 1.

Table 1. Basic wind pressures for the four wind zones

Wind zone	Site wind speed (m/s)	Basic wind pressure (kPa)	Design wind uplift pressure for rafters/trusses (kPa)	Design wind uplift pressure for periphery purlins (kPa)
Low	32	0.62	0.68	1.02
Medium	37	0.82	0.90	1.35
High	44	1.16	1.28	1.92
Very High	50	1.50	1.65	2.48

5.2 NZS 1900 Chapter 6.1 Purlin connections

It can most probably be assumed that most purlins in Chapter 6.1 houses were 3" x 2" on the flat and that these would have been nailed with two 4" nails per rafter. The contributing area to each connection to the rafter = 0.9 x 0.9 = 0.81 m^2. Using the pressures in Table 1, the expected uplift forces on the purlin connections are the product of the uplift pressure and the contributing area. These are given in Table 2.

From NZS 3603:1993 (SNZ 1993), the withdrawal strength of the two nails can be calculated.

For **Rimu** rafters:

The strength group is J3.

For a 4 mm diameter nail, the withdrawal load is 20 N/mm x 51 mm = **1.02 kN**

Thus, the strength of two nails is **2.04 kN**.

Table 2. Uplift forces on Chapter 6.1 Purlin connections

Wind zone	Wind uplift pressure (kPa)	Uplift force (kN)
Low	1.02	0.83
Medium	1.35	1.09
High	1.92	1.56
Very High	2.48	2.01

For **Radiata Pine and Douglas Fir** rafters:

The strength group is J5.

For a 4 mm diameter nail, the withdrawal load is 7.8 N/mm x 51 mm = **0.40 kN**

Thus, the strength of two nails is **0.80 kN**.

Although no account has been taken of the roof self-weight, the suggestion from this analysis is that the Rimu purlins ought to be able to resist all wind loads. The likelihood that Radiata Pine and Douglas Fir purlins in periphery areas would detach from the rafters under Very High, High and Medium wind loads is suggested. However, it is probable that only the edges of roofs of Chapter 6.1 houses in Very High wind areas would be at risk.

5.3 NZS 1900 Chapter 6.1 Rafter connections

The maximum spacing of rafters with purlins was 36”. Each rafter was required to be secured to the top plate with double skew nails. It would not be expected that the withdrawal of these nails from the plate would be any better than the purlins from the rafters.

Therefore the strength of the **Rimu** rafter to **Rimu** plate connection is assumed to be **2.04 kN**.

The strength of the **Radiata Pine and Douglas Fir** rafter to **Radiata Pine and Douglas Fir** plate connection is assumed to be **0.80 kN**.

For Radiata Pine and Douglas Fir top plates, required wires connecting the rafters directly to the studs will improve the hold-down capacity of the connection, provided the wires have not corroded. The connection strength is therefore assumed in this analysis to be the same as for Rimu timber (**2.04 kN**).

The maximum rafter size in Chapter 6.1 is 6” x 2” and this has a maximum span of 12 ft (3.66 m). The contributing area to the plate connection is therefore 3.66 m x 0.9 m / 2 = 1.65 m^2. An estimate of dead load is 0.9 x 0.2 kPa = 0.18 kPa, where 0.9 is the load combination factor in the loadings standard (SNZ 2002).

The net uplift forces on the rafter to plate connections are given by the wind uplift pressure minus the dead load pressure multiplied by the contributing area. These loads are given in Table 3.

This suggests that the rafter connection to the top plate could be overstressed in the Very High wind zone.

Table 3. Nett uplift forces on Chapter 6.1 Rafter to plate connections

Wind zone	Wind uplift pressure (kPa) (from Table 1)	Dead load pressure (kPa)	Uplift load on connection (kN)
Low	0.68	0.18	0.83
Medium	0.90	0.18	1.19
High	1.28	0.18	1.82
Very High	1.65	0.18	2.42

5.4 NZS 3604:1978 Purlin connections

With this standard came the introduction of **wind areas**, which were geographically aligned. The speed limits were given as:

Low wind speed area – not exceeding 35 m/s

Medium wind speed area – exceeding 35 m/s but not exceeding 40 m/s

High wind speed area – exceeding 40 m/s.

There was no stated upper limit on the wind speed for the High wind speed area.

With the introduction of this standard, purlin sizes for combinations of span and spacing were tabulated. For light roofs the smallest contributing area was 0.36 m^2,for which a fixing was designated and the largest contributing area was 1.44 m^2.

The factored dead load of the roof is estimated to be 0.2 kPa. Therefore, the nett uplift pressures are calculated by subtracting the roof dead load from the design wind uplift pressures in Table 1. These are presented in Table 4.

Table 4. Nett uplift pressures on NZS 3604:1978 Purlins at roof edges

Wind zone	Nett uplift pressure on purlins at roof edge (kPa)
Low	0.82
Medium	1.15
High	1.72
Very High	2.28

A single 100 x 3.75 mm nail was required to secure the purlin on the smallest area at the edge of a roof in all wind areas.

For High wind areas 2 – 100 x 3.75 mm skewed nails plus one wire dog were required for the edge. The wire dog was omitted in the body of the roof. For Medium and Low wind areas 2 – 100 x 3.75 mm skewed nails only were required.

The strengths of such connections (assuming all framing is Radiata Pine), calculated from NZS 3603, are as follows:

1 – 100 x 3.75 mm nail: 7.8 x 60 (estimated) = **0.47 kN**. It should be noted that in the 1999 issue of NZS 3604 the capacity of 1 – 100 x 3.75 mm one nail is given as **0.4 kN**.

2 – 100 x 3.75 mm skewed nails: 2 x 7.8 x 50 (estimated) = **0.78 kN**. It should be noted that in the 1999 issue of NZS 3604 the capacity of 2 – 100 x 3.75 mm skewed nails is given as **0.7 kN**.

2 – 100 x 3.75 mm skewed nails plus one wire dog: **2.7 kN** (from NZS 3604:1999).

Therefore, the single 100 mm nail securing an area of 0.36 m^2 will be subject to the following uplifts in a design event:

Very High: 2.28 x 0.36 = 0.82 kN

High: 1.72 x 0.36 = 0.62 kN

Medium: 1.15 x 0.36 = 0.41 kN

Low: 0.80 x 0.36 = 0.29 kN.

Such a connection is likely to be suitable in the Low and Medium wind zones but will be overstressed in the High and Very High wind zones.

The pair of skewed nails and a wire dog securing an edge area of 1.44 m^2 in a Very High wind zone will be subject to a nett uplift force of:

(2.48 (from Table 1) – 0.2 kPa) x 1.44 m^2 = **3.28 kN** in a design event. In a High wind zone, the uplift force will be 1.72 x 1.44 = **2.48 kN**.

Since the strength of this connection is given as 2.7 kN in NZS 3604:1999, it is expected that the connection could be overstressed if the wind speed exceeded:

$$V = \sqrt{\frac{\left(2.7/1.44 + 0.2\right)}{1.1x1.5x1000x0.6}} = 46m/s$$

which would cover about two-thirds of the currently assigned Very High wind zone structures.

In a Medium wind zone, the uplift force will be 1.15 kPa x 1.44 m^2 = **1.66 kN**. In a Low wind zone, the uplift force will be 0.82 kPa x 1.44 m^2 = **1.18 kN**.

In the body of a roof, the local coefficient, K_l, is 1.0 (SNZ 2002). Therefore, the current uplift pressures for the four wind zones are as follows:

Very High: 1.65 -0.2 = **1.45 kPa**

High: 1.28 -0.2 = **1.08 kPa**

Medium: 0.9 -0.2 = **0.7 kPa**

Low: 0.68 – 0.2 = **0.48 kPa.**

The contributing area for a two nail (0.7 kN capacity) connection in the body of a NZS3604:1978 High wind area roof is 0.9 x 0.9 = 0.81 m^2.

Hence the uplift loads are:

Very High: 1.45 x 0.81 = **1.17 kN**

High: 1.08 x 0.81 = **0.87 kN.**

It can be seen that in both instances the connection will be overstressed.

The contributing area for a one nail (0.4 kN capacity) connection in the body of a NZS3604:1978 Medium or Low wind area roof is also 0.9 x 0.9 = 0.81 m^2.

Hence the uplift loads are:

Medium: 0.7 x 0.81 = **0.57 kN**

Low: 0.48 x 0.81 = **0.39 kN.**

It can be seen that in the Medium wind zone that the connection will be overstressed, but the connection will suffice in the Low wind zone.

5.5 NZS3604:1978 Rafter connections

Several combinations of potential loading and resisting measures are included in the nailing schedule of this standard. Using the maximum spans from the rafter section of the standard for the rafter spacings, the contributing areas can be calculated as follows:

For light roofs in High wind areas, contributing area = 6.05/2 x 0.9 = 2.72 m^2; or

For light roofs in High wind areas, contributing area = 5.55/2 x 1.2 = 3.33 m^2; require

2 – 100 x 3.75 mm skewed nails plus two wire dogs: **4.7 kN** (from NZS 3604:1999).

For light roofs in Medium wind areas, contributing area = 5.55/2 x 1.2 = 3.33 m^2 require

2 – 100 x 3.75 mm skewed nails plus two wire dogs: **4.7 kN** (from NZS 3604:1999).

For such roofs in the current Very High wind zone, the expected uplift force is (1.65 – 0.3) x 3.33 = 4.5 kN. <u>Hence the two skewed nails plus two wire dog connections would likely be suitable for this eventuality</u>.

However, all other situations in NZS 3604:1978 require only 2 – 100 x 3.75 mm skewed nails and the strength of these is **0.7 kN**. The gap between the strengths of these two connections is very large and there are likely to be many houses built between 1964 and 1978 with inadequate rafter to top plate connections.

The uplift pressures in the NZS 3604:1999 Very High, High, Medium and Low wind zones are respectively 1.65 kPa, 1.28 kPa, 0.90 kPa and 0.68 kPa (see Table 1). Assuming a 0.2 kPa roof dead weight, the respective nett uplifts are 1.45 kPa, 1.08 kPa, 0.7 kPa and 0.48 kPa.

Rafters of buildings now in the current Very High wind zone, where the roof did not require wire dogs in 1978, could only have a connection contributing area of 0.7/1.45 = 0.48 m^2. This would involve the use of underpurlins, also with skew nailed connections, to achieve reasonable rafter spans. The acceptable rafter spans would increase for the lower wind zones.

5.6 NZS 3604:1978 Truss connections

Roof trusses were becoming a popular method of “framing” a roof by 1978. The design of roof trusses was considered to be outside the scope of the NZS 3604 standard. However, minimum capacities were specified for the connections between the truss and the top plate of the wall. Two 100 mm skewed nails plus either two wire dogs or an alternative fixing of 5 kN capacity in tension were required. Based on the tabulated strengths in NZS 3604:1999, the capacity of the skewed nails plus wire dogs is **4.7 kN**.

The maximum spacing of trusses supporting light roofs was set at 1.2 m and the maximum span at 12 m, with a 750 mm maximum eaves overhang. The greatest majority of light roofs are pitched between 20º and 30º. A typical light roof, including framing and a ceiling, is approximately 0.2 kPa for use with wind uplift (Shelton 2007). The external pressure coefficient for the roof will be approximately -0.6, plus an internal coefficient of +0.3, giving a total uplift coefficient of -0.9. The nett uplifts for the four wind zones are given in Table 5 for the load combination of 0.9G-W.

Table 5. Nett uplifts on typical light roof trusses

Wind zone	Basic wind pressure (kPa)	Uplift pressure (kPa)	Factored dead load pressure (kPa)	Nett uplift pressure (kPa)
Low	**0.61**	**0.55**	**0.18**	**0.37**
Medium	**0.82**	**0.74**	**0.18**	**0.56**
High	**1.16**	**1.04**	**0.18**	**0.86**
Very High	**1.50**	**1.35**	**0.18**	**1.17**

Therefore, for a 12 m span truss with 1.2 m spacing and a 750 mm eaves overhang, the uplift forces at the plate are:

Low wind zone: 0.37 x 1.2 x (12/2+.75) = **3.0 kN** (two skewed nails + two wire dogs provided)

Medium wind zone: 0.56 x 1.2 x (12/2+.75) = **4.5 kN** (two skewed nails + two wire dogs provided)

High wind zone: 0.86 x 1.2 x (12/2+.75) = **7.0 kN** (two skewed nails + four wire dogs provided)

Very High wind zone: 1.17 x 1.2 x (12/2+.75) = **9.5 kN** (two skewed nails + U strap provided)

Hence, trusses supporting a light roof and with a span up to 7.6 m in a High wind zone will be suitably secured. In a Very High wind zone, the maximum span with the specified fixing is 5.2 m.

5.7 NZS 3604:1984 Purlin connections

A maximum wind speed of 50 m/s for the High wind zone was introduced. A few houses may have been built between 1978 and 1984 in areas where the wind speed was greater than 50 m/s, but the number is expected to be few compared to the total housing stock.

There was no change to the fixing schedule in the 1984 standard from the 1978 standard. Special fixing provisions were introduced for skillion type roofs, but again the number of houses affected is expected to be few.

5.8 NZS 3604:1984 Rafter connections

A new provision for light roofs in the Low wind exposure was introduced in this version of the standard. When the rafter spacing exceeded 900 mm and the rafter span exceeded 4.5 m in the Low wind area, one skew nail plus two wire dogs were required to secure the rafter to the top plate. Otherwise, only two skewed nails were required.

The contributing area to the connection is therefore 4.5/2 x 0.9 = 2.025m^2. The nett uplift pressure is 0.47 kPa (see section 5.5). This provides an uplift force of 2.025 x 0.47 = **0.95 kN**. Given that the established strength of two skewed nails is 0.7 kN, there are likely to be some roofs in the Low wind zone that do not fit within the span criteria for skew nails plus wire dogs, and these have a potential to fail.

5.9 NZS 3604:1984 Truss connections

The truss securing provisions in the 1984 issue of NZS 3604 were the same as in the 1978 issue (see section 5.6).

5.10 NZS 3604:1990 Wind design philosophy change

With the publication of this version of NZS 3604 came the introduction of four wind zones, these being Very High, High, Medium and Low. These zones (cf "areas" in earlier issues) were not solely decided on geographic location. Factors such as local ground slope, shielding of buildings from other local obstructions and urban/rural/open location had an influence on the established wind "zone". For example, all houses built to NZS 3604:1984 and earlier issues were allocated to the "High wind area" in Wellington, whereas the 1990 issue resulted in houses being built in Wellington to any one of the four new "wind zones", depending on ground slope, shielding etc.

For comparison with other issues of the standard, the associated wind speeds are presented in Table 6. However, the change described above makes it impossible to make blanket predictions on design change effects based on geographic location alone.

Table 6. Comparison of maximum wind speeds for zones across issues of NZS 3604 (m/s)

Wind area/zone	NZS 3604:1978 (Wind area)	NZS 3604: 1984 (Wind area)	NZS 3604: 1990 (Wind zone)	NZS 3604:1999 (Wind zone)
Very High	Not defined	Not defined	50	50
High	No limit	50	44	44
Medium	40	40	37	37
Low	35	35	32	32

5.11 NZS 3604:1990 Purlin connections

In 1990 the wind pressure for the High wind zone dropped to ($44^2/50^2$) = 77% of that for the 1984 issue; the Medium wind zone dropped to 85% of that for the 1984 issue; the Low wind zone dropped to 84% of that for the 1984 issue.

However, the requirements for purlin fixings in this issue did not change for these three wind zones/areas. Two new requirements were introduced to cover Very High wind situations, these being two skew nails plus two wire dogs in the edge zone when the contributing area was up to 1.44 m^2, and two skew nails plus one wire dog when the contributing area was up to 0.81 m^2 in the body of the roof.

From section 5.4, the Very High wind pressure in the edge area of the roof is 2.28 kPa. The uplift force on the joint is therefore 2.28 x 1.44 = 3.28 kN. Compare this with the connection strength from NZS 3604:1999 of 4.7 kN, indicating that the connection should remain secure. If the philosophy change referred to in section 5.9 meant that the house was now located in a lower wind zone than Very High, the fixing would have more reserve strength. However, if the house was originally in a Low wind area, and is now identified as being in a Very High wind zone, then the single nail purlin connection with a strength of 0.4 kN would be totally inadequate.

In the body of the roof, the nett Very High wind uplift load is 1.45 kPa (from section 5.4) x 0.81 = 1.17 kN. The connection strength is 2.7 kN (from NZS 3604:1999), again indicating that the connection should remain secure. However, there are other NZS 3604:1990 purlin span/spacing combinations that have fixings that do not achieve the demands stated in or derived from NZS 3604:1999 (see Table 7). An inspection of the table suggests that generally in all areas and wind zones where the purlin spacing is greater than 400 mm, the addition of a single wire dog to the existing NZS 3604:1990 purlin connection would provide sufficient capacity.

5.12 NZS 3604:1990 Rafter connections

As for purlins, the fixing requirements did not change for the Low, Medium and High wind zones, but the demand pressures dropped because of the new zoning regime. This is expected to cover off the weak connection situations identified in the 1984 issue of NZS 3604.

A new fixing case for the Very High wind zone was introduced. This was the inclusion of a cyclone tie of 16 kN capacity when the rafter span exceeded 2.5 m and the spacing exceeded 900 mm. From the standard, the maximum rafter span is 6.2 m and the maximum spacing is 1.2 m. From these, the maximum contributing area to the joint is 6.2/2 x 1.2 = 3.72 m^2. From section 5.3, the uplift force is 1.5 kPa x 1.1 X 3.72 = 6.14 kN. Without including the dead weight of the roof, it can be seen that the cyclone tie is well able to resist the uplift forces.

5.13 NZS 3604:1990 Truss connections

The truss securing provisions in the 1990 issue of NZS 3604 were the same as in the 1978 issue (see section 5.6), with the added requirement that when a truss in a light roof had a clear span exceeding 7.2 m, the top plate was required to be fixed to the studs at not more than 900 mm centres with pairs of wire dogs.

5.14 NZS 3604:1999 Purlin connections

Four fixing types are specified in the 1999 issue of the standard, ranging from a single nail (0.4 kN capacity) to two nails (0.7 kN capacity), to two nails plus one wire dog (2.7 kN capacity), to two nails and two wire dogs (4.7 kN capacity). An inspection of the fixing strengths required in the standard for purlins of light roofs in all wind zones suggests that the minimum fixing required is two nails plus one wire dog (2.7 kN capacity). However, the purlin table sets the fixing requirement for the purlin based on the maximum span and spacing for the purlin.

It is possible to back calculate the demand loads for lesser spans and spacings for comparison with houses built to the 1990 issue of the standard, and these are presented in Table 7 below. The upper table provides the NZS 3604:1999 required purlin fixing strengths and the shading identifies the fixing available to provide the resistance. The lower table gives the strengths of the nominated fixings for the same combinations of wind load, purlin spacing and purlin span in NZS 3604:1990. If the cell is shaded red in the lower table, this means that the fixing has insufficient strength.

An inspection of the table suggests that there are quite a number of instances where the NZS 3604:1990 connection is sub-standard in terms of the NZS 3604:1999 requirements. Of particular interest are the instances where the periphery connection is weak because these are the areas where, if a roof cladding is going to lift off, the lifting will usually initiate.

Table 7. Comparison of purlin fixing strengths and demands

Required Purlin fixing strengths (NZS 3604:1999)

Purlin span (mm)	Purlin spacing (mm)	Low wind zone		Medium wind zone		High wind zone		Very high wind zone	
		Main	Periphery	Main	Periphery	Main	Periphery	Main	Periphery
600	400	0.2	0.2	0.2	0.3	0.3	0.4	0.4	0.6
	900	0.3	0.5	0.5	0.7	0.7	1.0	0.9	0.8
	1200	0.5	0.7	0.7	0.9	0.9	1.3	1.2	1.7
900	400	0.2	0.3	0.3	0.5	0.5	0.7	0.6	0.9
	900	**0.5**	**0.8**	**0.7**	**1.1**	**1.0**	**1.5**	**1.3**	**1.2**
	1200	**0.7**	**1.0**	**1.0**	**1.4**	**1.4**	**2.0**	**1.8**	**2.6**
	1800	**1.0**	**1.5**	**1.4**	**2.1**	**1.6**	**2.3**	**2.0**	**3.1**
1200	400	0.3	0.5	0.4	0.6	0.4	0.6	0.5	0.8
	900	0.7	1.1	0.9	1.3	0.9	1.4	1.2	1.7
	1000	0.8	1.2	1.0	1.4	1.0	1.5	1.3	1.9
	1200	**0.9**	**1.4**	**1.2**	**1.7**	**1.2**	**1.8**	**1.6**	**2.3**
	1300	**1.0**	**1.5**	**1.2**	**1.7**	**1.2**	**1.8**	**1.6**	**2.3**
	1700	**1.3**	**1.9**	**1.6**	**2.3**	**1.5**	**2.2**	**2.0**	**2.9**

Notes:

1. The bold font figures are taken directly from NZS 3604:1999 Table 10.9 MSG8

2. The normal font figures are derived from the NZS 3604:1999 figures on the basis of contributing area

Key to shading

1 nail

2 nails

2 nails and one wire dog

2 nails and two wire dogs

NZS3604:1990 provided capacities

Purlin span (mm)	Purlin spacing (mm)	Low wind zone		Medium wind zone		High wind zone		Very high wind zone	
		Main	Periphery	Main	Periphery	Main	Periphery	Main	Periphery
600	400	0.4	0.6	0.4	0.6	0.4	0.6	0.4	0.6
	900	0.4	0.7	0.4	0.7	0.7	0.7	2.7	0.7
	1200	0.4	0.7	0.4	0.7	0.7	0.7	2.7	0.7
900	400	0.4	**0.4**	0.4	**0.4**	0.7	**0.4**	2.7	**0.4**
	900	**0.4**	**0.7**	**0.4**	**0.7**	**0.7**	**0.7**	**2.7**	**0.7**
	1200	0.7	0.7	0.7	0.7	0.7	2.7	0.7	4.7
	1800	NA	NA	NA	NA	NA	NA	NA	NA
1200	400	**0.4**	**0.6**	**0.4**	**0.6**	**0.4**	**0.6**	**0.4**	**0.6**
	900	0.7	0.7	0.7	0.7	0.7	2.7	0.7	4.7
	1000	0.7	0.7	0.7	0.7	0.7	2.7	0.7	4.7
	1200	**0.7**	**0.7**	**0.7**	**0.7**	**0.7**	**2.7**	**0.7**	**4.7**
	1300	NA	NA	NA	NA	NA	NA	NA	NA
	1700	NA	NA	NA	NA	NA	NA	NA	NA

Notes:

1. The bold font figures are taken directly from NZS 3604:1990 Table A1

2. The normal font figures are derived from the NZS 3604:1990 figures based on the maximum area limits

3. NA means not allowed by NZS 3604:1990

4. Red shading means that the fixing capacity is less than required by NZS 3604:1999

6. SUMMARY OF DEMANDS AND RESISTANCES

It has only been possible to concisely tabulate the resistance provided by, and demands placed on, connections for roofs that have been built to construction standards for timber framing that existed prior to 1980. These are produced in Table 8 and Table 9. Later issues of NZS 3604 have several parameters that have an influence on the connection design. Detailed descriptions of the required retrofit solutions may be found in Appendix B of this report.

Clearly from the above sections, there are many instances where houses built before 1990 may have purlin and rafter connection strengths that are insufficient to match the current wind load demands.

Table 8. NZS 1900 Chapter 6.1 Resistances and demands

Joint	Wind zone	Chapter 6.1 Resistance	Demand	Overstressed?
Purlin/rafter	Very High	Rimu 2.04 kN	2.01 kN	No
		Pine 0.8 kN		Yes
	High	Rimu 2.04 kN	1.56 kN	No
		Pine 0.8 kN		Yes
	Medium	Rimu 2.04 kN	1.09 kN	No
		Pine 0.8 kN		Yes
	Low	Rimu 2.04 kN	0.83 kN	No
		Pine 0.8 kN		No
Rafter/plate	Very High	R & P 2.04 kN	2.42 kN	Yes
	High	R & P 2.04 kN	1.82 kN	No
	Medium	R & P 2.04 kN	1.19 kN	No
	Low	R & P 2.04 kN	0.83 kN	No

R & P = Rimu and Pine

Table 9. NZS 3604:1978 Resistances and demands

Joint	Wind zone	Roof area	Contrib Area (m^2)	NZS 3604:1978 Resistance (kN)	Demand (kN)	Over-stressed?
Purlin/rafter	Very High	Edge	0.36	0.47	0.82	Yes
	High	Edge	0.36	0.47	0.62	Yes
	Medium	Edge	0.36	0.47	0.41	No
	Low	Edge	0.36	0.47	0.29	No
	Very High	Edge	1.44	2.7	3.28	Yes
	High	Edge	1.44	2.7	2.48	No
	Medium	Edge	1.44	0.7	1.66	Yes
	Low	Edge	1.44	0.7	1.15	Yes
	Very High	Body	0.81	0.7	1.17	Yes
	High	Body	0.81	0.7	0.87	Yes
	Medium	Body	0.81	0.4	0.57	Yes
	Low	Body	0.81	0.4	0.39	No
Rafter/plate	Very High			R & P 2.04 kN	3.23 kN	Yes
	High			R & P 2.04 kN	2.42 kN	Yes
	Medium			R & P 2.04 kN	1.58 kN	No
	Low			R & P 2.04 kN	1.07 kN	No

R & P = Rimu and Pine

7. RETROFIT SOLUTIONS

7.1 Roof claddings

An older roof should first be inspected to determine the condition of the existing nails. Any nails that have lost their heads should be replaced. Corrugated galvanised steel claddings that have been fixed with screws and washers are likely to have a much greater resistance to loss of the cladding in high winds than nailed claddings. Retrofitting of these roofs will not be required.

Roofs that are fixed with lead head nails that are in NZS 3604:1999 High and Very High wind zones can be improved at low cost by the addition of a new screw fixing on the crests between the existing nails, along the rows adjacent to the eaves, ridge and gable ends. Extra fixings are also recommended where sheet ends overlap. If it can be determined that the cladding is fixed through sarking boards rather than purlins, then the additional fixings should be placed slightly further up the slope of the roof so that they penetrate the adjacent sarking board rather than the same board. This will ensure that the uplift loads from the wind are spread over the two boards rather than being concentrated on one only. The same principle should be employed at the ridge, although in this case the new row of fixings will generally need to be slightly down the slope.

7.2 Purlin to rafter connections

For light corrugated steel roofs of houses built before 1999, the inclusion of a single wire dog (if not already in existence) on the purlin to rafter connection in the periphery areas of a roof would largely move the strength of the connection to a level greater than the expected demand in these areas in all wind zones. Such a retrofit would not be required on roofs where the purlin span and spacing were respectively no more than 600 mm and 400 mm.

Practically, such an addition could be achieved with little disruption to the existing structure. Most junctions could be accessed via the roof space, although the critical purlin will generally be the one at the eaves, where suctions are known to be highest. Retrofitting of the eaves purlin connections would require the soffit lining to be removed for access and then replaced. Such a removal would also provide access to the roof frame to top plate connection.

7.3 Rafter to plate connections

No retrofit solutions for rafter to top plate connections are proposed for heavy roof claddings such as concrete and clay tiles.

7.3.1 Pre-1978 houses

As discussed in section 5.3, it is expected that rafters in houses built prior to 1978 and located in Very High wind zones (in NZS 3604:1999 terms) may not be adequately connected to wall plates. For houses in Very High wind zones that were built before 1978, additional fixings will be required between the rafters and the wall top plates.

Practical issues such as access to the connection dictate the method of retrofitting that can be undertaken. An appropriate retrofit for the Very High wind zone is to add a single "L" bracket to one side of the rafter where it crosses the plate, if access can be achieved via the ceiling space. The bracket can be nailed into the rafter with six 30 mm x 3.15 mm diameter galvanised nails and then screw fixed to the top surface of the plate with two Type 17 14g x 50 mm hex head galvanised screws. Proprietary products are available for this purpose.

Alternatively, if the soffit lining is removed, a 25 mm x 0.9 mm galvanised steel strap can be installed that passes down the side of the rafter and twists through 90º to then be fixed to the top plate and the rafter with four 30 mm x 3.15 mm diameter galvanised nails each.

7.3.2 1978-1990 houses

For houses built in the Low wind area, and which are now considered to be in a Low wind zone, rafters with a rafter/plate connection contributing area between 1.5 m^2 and 2.0 m^2 would benefit from additional fixings. An appropriate retrofit is to add a single "L" bracket to one side of the rafter where it crosses the plate. This can be nailed into the rafter with four 30 mm x 3.15 mm diameter galvanised nails and then screw fixed to the top surface of the plate with two Type 17 14g x 50 mm hex head galvanised screws. Proprietary products are available for this purpose. Rafters with a greater contributing area to the connection will not require additional fixings.

For houses built in the Low wind area, and which are now considered to be in a Medium wind zone, rafters with a rafter/plate connection contributing area between 1.0 m^2 and 2.0 m^2 would benefit from additional fixings. An appropriate retrofit is to add a single “L” bracket to one side of the rafter where it crosses the plate. This can be nailed into the rafter with four 30 mm x 3.15 mm diameter galvanised nails and then screw fixed to the top surface of the plate with two Type 17 14g x 50 mm hex head galvanised screws. Proprietary products are available for this purpose. Rafters with a greater contributing area to the connection will not require additional fixings.

For houses built in the Low wind area, and which are now considered to be in a High or Very High wind zone, rafters with a rafter/plate connection contributing area up to 2.0 m^2 would benefit from additional fixings. An appropriate retrofit is to add a single “L” bracket to one side of the rafter where it crosses the plate. This can be nailed into the rafter with four 30 mm x 3.15 mm diameter galvanised nails and then screw fixed to the top surface of the plate with two Type 17 14g x 50 mm hex head galvanised screws. Proprietary products are available for this purpose. Rafters with a greater contributing area to the connection will not require additional fixings.

For houses built in the Medium wind area, but which would now be assessed as being in a Low wind zone, no retrofit measures would be required.

For houses built in the Medium wind area, but which would now be assessed as being in a Medium wind zone, rafters with a rafter/plate connection contributing area between 1.0 m^2 and 2.3 m^2 would benefit from additional fixings. An appropriate retrofit is to add a single “L” bracket to one side of the rafter where it crosses the plate. This can be nailed into the rafter with four 30 mm x 3.15 mm diameter galvanised nails and then screw fixed to the top surface of the plate with two Type 17 14g x 50 mm hex head galvanised screws. Proprietary products are available for this purpose. Rafters with a greater contributing area to the connection will not require additional fixings.

For houses built in the Medium wind area, but which would now be assessed as being in a High wind zone, rafters with a rafter/plate connection contributing area between 0.7 m^2 and 2.3 m^2 would benefit from additional fixings. An appropriate retrofit is to add a single “L” bracket to one side of the rafter where it crosses the plate. This can be nailed into the rafter with four 30 mm x 3.15 mm diameter galvanised nails and then screw fixed to the top surface of the plate with two Type 17 14g x 50 mm hex head galvanised screws. Proprietary products are available for this purpose. Rafters with a greater contributing area to the connection will not require additional fixings.

For houses built in the Medium wind area, but which would now be assessed as being in a Very High wind zone, two checks are required. If the contributing area to the connection is greater than 3.2 m^2 and nails and wire dogs are already in place, an additional fixing is still required. If the contributing area is between 0.5 m^2 and 3.2 m^2 and no wire dogs are in place, an additional fixing will be required. In both instances, an appropriate retrofit is to add a single “L” bracket to one side of the rafter where it crosses the plate. This can be nailed into the rafter with four 30 mm x 3.15 mm diameter galvanised nails and then screw fixed to the top surface of the plate with two Type 17 14g x 50 mm hex head galvanised screws. Proprietary products are available for this purpose.

For houses built in the High wind area, but which would now be assessed as being in a Low wind zone, no retrofit is required.

For houses built in the High wind area, but which would now be assessed as being in a Medium wind zone, rafters with a rafter/plate connection contributing area between

2.7 m^2 and 3.7 m^2 (but that have no wire dogs in place) would benefit from additional fixings. An appropriate retrofit is to add a single “L” bracket to one side of the rafter where it crosses the plate. This can be nailed into the rafter with four 30 mm x 3.15 mm diameter galvanised nails and then screw fixed to the top surface of the plate with two Type 17 14g x 50 mm hex head galvanised screws. Proprietary products are available for this purpose.

For houses built in the High wind area, but which would now be assessed as being in a High wind zone, rafters with a rafter/plate connection contributing area between 1.8 m^2 and 3.7 m^2 (but that have no wire dogs in place) would benefit from additional fixings. An appropriate retrofit is to add a single “L” bracket to one side of the rafter where it crosses the plate. This can be nailed into the rafter with four 30 mm x 3.15 mm diameter galvanised nails and then screw fixed to the top surface of the plate with two Type 17 14g x 50 mm hex head galvanised screws. Proprietary products are available for this purpose.

For houses built in the High wind area, but which would now be assessed as being in a Very High wind zone, several checks are required. If the contributing area to the connection is greater than 3.25 m^2, and nails and wire dogs are already in place, an additional fixing is still required. An appropriate retrofit is to add a single “L” bracket to one side of the rafter where it crosses the plate. This can be nailed into the rafter with four 30 mm x 3.15 mm diameter galvanised nails and then screw fixed to the top surface of the plate with two Type 17 14g x 50 mm hex head galvanised screws. Proprietary products are available for this purpose.

If the contributing area to the connection is greater than 3.25 m^2, and nails and wire dogs are not in place, an additional fixing is still required. An appropriate retrofit is to add a single “L” bracket to one side of the rafter where it crosses the plate. This can be nailed into the rafter with eight 30 mm x 3.15 mm diameter galvanised nails and then screw fixed to the top surface of the plate with four Type 17 14g x 50 mm hex head galvanised screws. Proprietary products are available for this purpose.

If the contributing area to the connection is between 1.3 m^2 and 3.25 m^2 and nails and wire dogs are not in place, an additional fixing is still required. An appropriate retrofit is to add a single “L” bracket to one side of the rafter where it crosses the plate. This can be nailed into the rafter with eight 30 mm x 3.15 mm diameter galvanised nails and then screw fixed to the top surface of the plate with four Type 17 14g x 50 mm hex head galvanised screws. Proprietary products are available for this purpose.

7.3.3 1990-1999 houses

For houses built in the NZS 3604:1990 Low and Medium wind zones no retrofit is required.

For houses built in the NZS 3604:1990 High wind zone, additional fixings are required if the contributing area to the connection is between 1.8 m^2 and 3.7 m^2 and there are no wire dogs already in place. An appropriate retrofit is to add a single “L” bracket to one side of the rafter where it crosses the plate. This can be nailed into the rafter with four 30 mm x 3.15 mm diameter galvanised nails and then screw fixed to the top surface of the plate with two Type 17 14g x 50 mm hex head galvanised screws. Proprietary products are available for this purpose.

For houses built in the NZS 3604:1990 Very High wind zone, additional fixings are required if the contributing area to the connection is between 0.5 m^2 and 3.7 m^2 and there are no cyclone ties already in place. An appropriate retrofit is to add a single “L” bracket to one side of the rafter where it crosses the plate. This can be nailed into the rafter with four 30 mm x 3.15 mm diameter galvanised nails and then screw fixed to the top surface of the plate with two Type 17 14g x 50 mm hex head galvanised screws. Proprietary products are available for this purpose.

7.4 Truss to plate connections

No retrofit solutions for rafter to top plate connections are proposed for heavy roof claddings such as concrete and clay tiles.

For trusses spanning greater than 7.6 m in a High wind zone, or 5.2 m in a Very High wind zone, and that do not have more than two skewed nails plus two wire dogs, an additional fixing is required.

Access to the top plate is limited by the close proximity of the roof plane and no further access is available to the top plate unless the soffit lining is removed. An appropriate retrofit is to add a single “L” bracket to one side of the truss where it crosses the plate. This can be nailed into the truss with eight 30 mm x 3.15 mm diameter galvanised nails and then screw fixed to the top surface of the plate with two Type 17 14g x 50 mm hex head galvanised screws. Proprietary products are available for this purpose.

Alternatively, if the soffit lining is removed, a 25 mm x 0.9 mm galvanised steel strap can be installed that passes down the side of the truss and twists through 90º to then be fixed to the top plate and the truss with eight 30 mm x 3.15 mm diameter galvanised nails each. If the truss is seated directly over a stud, then the strap can be connected to the stud rather than to the plate.

7.5 Selection table

A selection table has been appended to this report (see Appendix B) that allows a user to decide the necessary retrofit solution required for the roof of a house of any vintage.

Entry to the table requires knowledge of the wind area that the house is located in, in terms of 1984 and earlier versions of the construction standard. Next, the user must know the wind zone that the house is located in, in terms of the 1990 and later versions of NZS 3604. Proposed retrofit solutions for the purlins, and rafters or trusses, are provided for each combination of wind area and wind zone.

For an individual house, it is a relatively simple process to decide whether any retrofitting is required. The process is as follows:

1. Determine the age of the house.
2. Determine the current wind zone for the location from NZS 3604:1999.
3. Determine the wind zone (for houses constructed since 1990) or wind area for houses built between 1978 and 1990 (Figure 3). For houses built earlier than 1978, no recognition of wind area is given.
4. Determine the spacing of purlins/battens.
5. Determine the spacing of rafters/trusses.
6. Calculate the contributing area to the purlin to rafter/truss joint (= purlin spacing x rafter/truss spacing) and ascertain the current purlin fixing, if visible.
7. Calculate the contributing area to the rafter/truss to plate connection. For rafters, this may be taken equal to the rafter spacing x the half the span of the rafter. For trusses, this may be taken equal to the truss spacing x half the span of the truss. The truss span will generally be equal to the building width. Ascertain the current fixing of the rafter/truss to the top plate.
8. From the retrofit selection table (Appendix B), determine whether a retrofit would be required and, if so, what this would be.

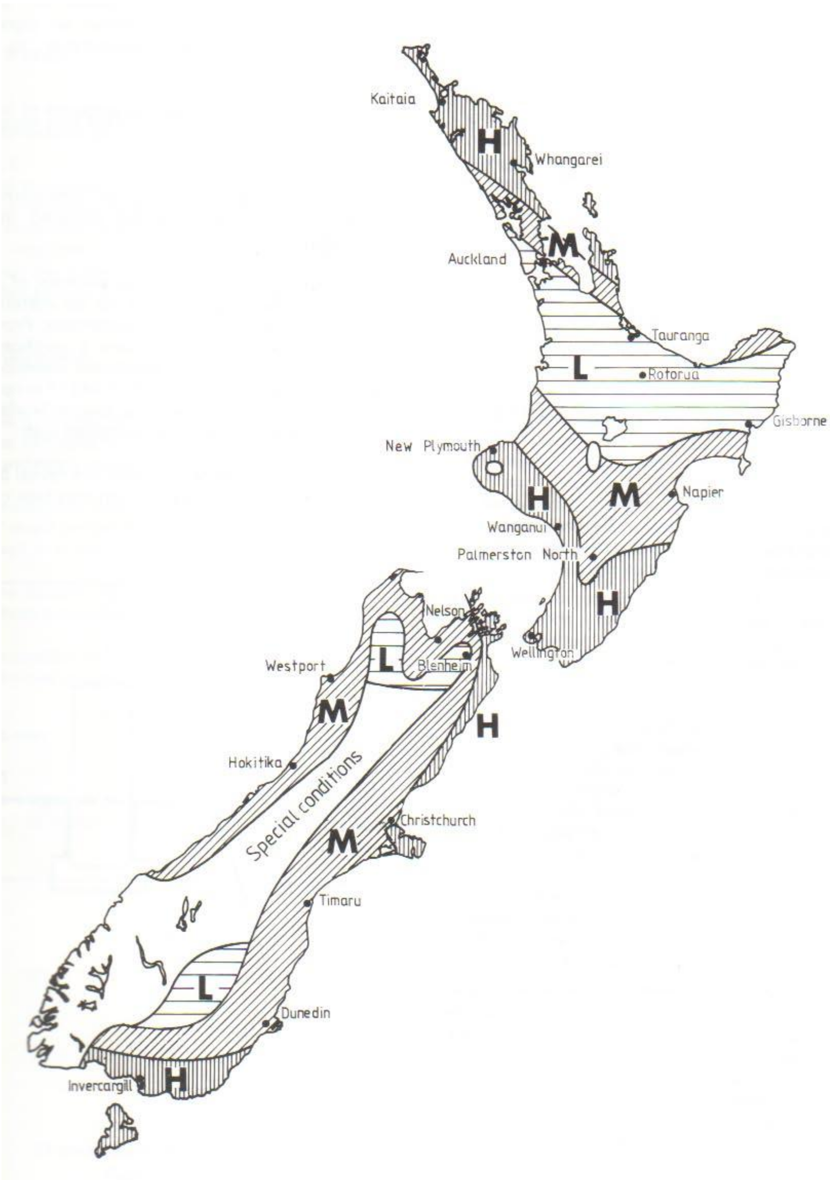

Figure 3. Wind areas for houses constructed before 1990 (copied from NZS 3604:1984)

8. COSTING OF PROPOSED SOLUTIONS

Having established the preferred technical solution, it remains to determine its cost. While it is of no interest to an individual home-owner BRANZ has attempted to estimate the accumulated costs over the country, if all retrofits were undertaken.

8.1 Potential retrofit costs for an average house

Should Z nails be required to strengthen the joint between the purlins and the rafters, the approximate cost of Z nails for an average sized house with rafters is $190. The estimated labour charge to install the Z nails is $943. To strengthen the connection between the rafters and the wall plates, the estimated cost is $164 for the "L" brackets and $896 for installation. This sums to a potential total cost of $2193.

Should Z nails be required to strengthen the joint between the purlins and the trusses, the approximate cost of Z nails for an average sized house with trusses is $102. The estimated labour charge to install the Z nails is $505, giving a total cost of $607 to strength the purlin to truss connection. To strengthen the connection between the rafters and the wall plates, the estimated cost is $117 for the “L” brackets and $640 for installation. This sums to a potential total cost of $1364.

8.2 Cumulative costs for retrofitting the complete housing stock

Because of the wide range of combinations of wind zones (not only across the country but within each Territorial Authority (TA)), roof cladding types, rafter or truss spacings and purlin spacings, it has been necessary to make many assumptions in the accumulation of the estimated total cost data.

The assumptions made in the cost analysis are as follows:

8.2.1 Houses constructed since 1999

It has been assumed that no houses constructed since 1999 would require retrofitting.

8.2.2 Roof material percentages

The total number of stand-alone houses constructed in the periods pre-1980, 1980-1989 and 1990-1999 in each TA has been taken from Quotable Value New Zealand (QVNZ 1998). The percentages of houses constructed with sheet metal roofs and metal tile roofs for these periods has been established based on a random sample of 565 houses taken across the country (Clark et al 2005). From this sample the assumed percentages are as given in Table 10.

Table 10. Percentages of sheet metal and metal tile roofs

	Pre-1980	1980-1989	1990-1999
Sheet metal	52.7	43.0	40.2
Metal tile	15.8	22.7	30.3

8.2.3 Wind zones

To simplify the process of the accumulation of costs, each TA was allocated a representative wind zone (Low, Medium, High or Very High) for the stock of houses contained within its area of jurisdiction. The determination of the representative wind zone was based on the wind region in which the majority of the TA fell: whether it fell within a lee zone; whether it was predominantly urban or rural; the general exposure level of properties in the TA; and the terrain. It should be noted that this is a gross simplification but one that is necessary in order to reasonably accumulate the costs.

8.2.4 Average house

The average house was assumed to be 16 m long by 8 m wide (total floor area of 128 m^2). The maximum purlin span was assumed to be 1.2 m for the trussed roof houses and 900 mm for the roofs with rafters.

8.2.5 Concentration of retrofit effort

Because the first weakness in roof construction for the resistance of wind loads is usually the loss of the connections at the eaves level, the retrofit solutions concentrated on ensuring that this area was appropriately retrofitted. For this reason, it was considered necessary to strengthen the connections between the purlins and the rafters/trusses over the first two rows of purlins from the eave. Similarly, the connection of the rafters to the top plates was seen as more critical than their connection to the ridge board. The addition of fixings to sheet steel roofs in the High and Very High wind zones has been included in the retrofit cost estimates.

Too many variables peculiar to each house prevent an accurate estimation of the amount of retrofit required. Therefore, it has been assumed that 12% of the sheet metal clad roofs and 5% of the metal tiled roofs will be in need of retrofitting when supported on rafters. When supported by trusses, the percentages have been assumed to be respectively 25% and 5%. While these percentages are not able to be substantiated, they were based on judgement, given the typical purlin, rafter and truss spacings encountered in the field and their relationships to the typical contributing area trigger points given in Appendix B.

8.2.6 Cost rates

The labour rate was assumed to be $40 per hour and the time expected to be taken to undertake a retrofit of an average house was assumed to be two days for the purlin connection retrofit and two days for the rafter/truss connection retrofit.

The allowed cost rates for the materials were assumed to be $1.70 per Z nail and $3.90 per "L" plate.

8.2.7 Accumulated cost for the country

A spreadsheet was created that took account of the factors described in sections 8.2.2 to 8.2.6 and which accumulated the retrofit costs over the whole country, if all retrofits were undertaken. The total cost estimated to retrofit affected roofs with rafters was $100,920,000 and to retrofit affected roofs with trusses was $122,240,000, giving a total cost of $223,160,000.

Readers are reminded that these estimates are based on broad assumptions. Individual home-owners are offered a tool to allow them to assess the potential vulnerability of their house and therefore decide whether they wish to undertake any retrofit measures and it is a matter of individual owner's choice. Because of this, it is unlikely that all retrofits would be undertaken and therefore the $223,160,000 is likely to significantly overestimate the actual investment.

While there are no plans at present for legislation to require structural upgrades of housing it could be introduced sometime in the future. Before any such system was introduced it would need to take account of climate change and be the subject of a regulatory impact assessment including cost-benefit studies. If introduced, it is likely to be in some graduated form (e.g. starting at a fraction of current National Building Standard for pre1930 housing).

9. CONCLUSION

This report predominantly covers the development of provisions over the years for the fixing of roof claddings and roof framing on houses because it is most usual for the roof or its cladding to be lost from a house before any other damage to the building occurs. The strengths of such fixing details are compared to the expected demands determined using modern loading standards, and retrofit solutions are suggested. The aim was to cause the minimum amount of invasion of the existing framing, although it may sometimes be necessary to remove and replace soffit linings to gain access to the rafter to plate connections to carry out the proposed retrofit.

The analyses have shown that there are deficiencies in the connections specified in the past for certain wind situations. Proposed retrofits attempt to strengthen the connection so that it will resist the potential wind loads, based on the requirements of recently published standards.

It was determined that there were a significant number of houses that would likely be in need of some retrofit. A distribution of estimated costs has been prepared for various retrofit scenarios. The range of cost spans from $607 to $2193, depending on the situation.

Home owners should note that houses that have been built to superseded standards are not required by law to undertake an upgrade to the structural system of their house unless that after an alteration there is a need to strengthen the house so that it will continue to comply with the structural provisions of the NZ Building Code to at least the same extent as before the alteration. This might occur, for example, if a house is relocated to a site which has a higher wind zone. In all cases, a building consent covering the alterations will be required and the new work will be required to satisfy the requirements of the NZ Building Code and its referenced building standards.

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APPENDIX A: EXTRACTS FROM RELEVANT STANDARDS

CONSTRUCTION STANDARDS

NZS 1900 Chapter 6.1: 1964 Construction requirements for buildings not requiring specific design – Division 6.1 – Timber

Clause 6.1.11.1 The wooden framework of all buildings shall be connected together in a secure manner.

Clause 6.1.11.2.3 Each weatherboard shall be securely fixed to each stud by one nail just above the lap. The nails used shall be not less than 2½ in. in length, and 3 in. nails shall be used for framing of Radiata pine or timbers of similar density.

Clause 6.1.11.3.1 Rafters shall be double skew nailed to the supporting plates. Purlins shall be securely fastened against uplift. Unless otherwise permitted by the Engineer, the lower density timbers such as Radiata Pine, Douglas Fir (Oregon), etc., used for rafters shall be further fixed at not more than 4 ft 6 in. centres with wiring, strapping, or other approved means. When plates are end nailed only to the studs, the required additional fixing shall securely connect the rafters to the studs.

NO apparent quantity provisions for the fixing of purlins against uplift.

Clause 6.1.11.3.2 Where the means of securing roof members against uplift as provided for above are for any reason considered by the Engineer to be inadequate, alternative or additional means of fixing shall be provided to his satisfaction.

Clause 6.1.35.1 All roofs shall be so framed and tied into the framework and supporting walls as to form an integral part of the whole building.

Clause 6.1.35.3 Provision to bolt top plates on masonry or concrete walls with 3/8 in. bolts at 4 ft 6 in. centres.

Clause 6.1.36.3 Rafters shall be neatly fitted and well spiked to the plates (*overridden surely by clause 6.1.11.3.1?*), ridge boards, valleys and hips.

Clause 6.1.40.4 Provision shall be made to prevent fabric roofing being lifted by wind.

NZS 3604:1978 Code of Practice for LIGHT TIMBER FRAME BUILDINGS not requiring specific design.

Wind <u>areas</u>:
Low – not exceeding 35 m/s
Medium – exceeding 35 m/s but not exceeding 40 m/s
High – exceeding 40 m/s (*no upper limit stated*)
Commentary states that if local severe effects (including an area designated "Special Conditions") are possible the standard cannot be applied.

Tornado effects ignored because of small affected area.

Lintels

Clause 6.6.1.5 Lintels supporting rafters or trusses of light roofs shall be secured against uplift in accordance with clause 6.6.1.6 where:

(a) High wind exposure:
    (i) The lintel span exceeds 1.5 m and the roof dimension S exceeds 8 m; or
    (ii) The lintel span exceeds 2.7 m.
(b) Medium wind exposure: The lintel span exceeds 2.7 m and the roof dimension S exceeds 8 m.

Clause 6.6.1.6 Each lintel required by clause 6.6.1.5 to be secured against uplift shall in addition to the fixing required by Appendix A be fixed at each end to a trimming stud which is fixed to floor framing, each fixing to be as shown in Figure 41 or an alternative fixing of 5 kN capacity in tension along the line of the trimming stud.

Fixing of exterior wall coverings
– weatherboards – prescriptive
– masonry veneer – prescriptive
– solid plaster – prescriptive
– other materials – according to manufacturer recommendations.

Windows – must comply with NZS 1900 Chapter 10.

Roof trusses

Clause 10.2.5 Anchorage.

Clause 10.2.5.1 The fixing of a roof truss at its support shall be as given by the drawings and specifications, but not less than two 100 mm skewed nails plus either one 4.9 mm wire dog or an alternative fixing of 5 kN capacity in tension against uplift.

Clause 10.2.5.2 In high wind exposure areas additional fixings complying with clause 10.2.5.3 shall be provided to the top plate and its supporting members of a wall supporting a truss that supports a light roof and exceeds 7.2 m span.

Clause 10.2.5.3 Where required by 10.2.5.2 the top plate shall have additional fixing to studs and lintels by pairs of 4.9 mm wire dogs at more than 900 mm centres, or an alternative fixing of 5 kN capacity in tension against uplift at not more than 900 mm centres.

Rafters

Clause 10.3.2.7 Rafters shall be fixed to top plates, wall plates, lintels and beams as shown in Figure 50 provided that the plumb cut of the birdsmouth shall not exceed one-quarter of the depth of the rafter at that point. (*Figure 50 makes no mention of the fixing type*).

Purlins

No specific mention in purlin clauses of fixing requirements.

Roof claddings

Clause 11.1.1 (b) Be of acceptable strength and durability.

Clause 11.1.2 Any roof cladding material specified in clauses 11.3 to 11.8 inclusive shall be accepted as complying with the relevant requirements of clause 11.1.1. Any other roof cladding material used in accordance with clause 2.3 shall be fixed to framing members in accordance with clearly presented and adequate technical information supplied by the manufacturer.

Appendix A. Nailing Schedule

Rafter to ridge board	75 x 3.15 or	4 (skewed)
	100 x 3.75	2 (end nailed)
Rafter to top plate	Mix of skewed 100 x 3.75 nails only and nails plus wire dogs depending on situation	2 (skewed)
Underpurlins and underpurlin struts	Mix of skewed 100 x 3.75 nails only and nails plus wire dogs depending on situation	2 (skewed) 2 wire dogs
Purlins to rafters	Light roofs Range from 1 – 100 x 3.75 nail to 2 – 100 x 3.75 skewed nails plus one wire dog Heavy roofs Anywhere 1200 mm x 900 mm max area – 100 x 3.75	1 to 2 (skewed) 2 (no skew req.)

NZS 3604:1984 Code of Practice for LIGHT TIMBER FRAME BUILDINGS not requiring specific design.

As for NZS 3604:1978 with some modifications and additions as follows:

Wind areas:
Low – not exceeding 35 m/s
Medium – exceeding 35 m/s but not exceeding 40 m/s
High – exceeding 40 m/s but not exceeding 50 m/s
Commentary states that if local severe effects (including an area designated "Special Conditions") are possible the standard cannot be applied.

Tornado effects ignored because of small affected area.

Lintels

Clause 6.6.1.5 Lintels supporting rafters or trusses of light roofs shall be secured against uplift in accordance with clause 6.6.1.6 where:

(a) High wind exposure:
    (i) The roof dimension S exceeds 6 m; or
    (ii) The lintel span exceeds 2.4 m and the roof dimension S exceeds 4 m.
(b) Medium wind exposure: The lintel span exceeds 2.7 m and the roof dimension S exceeds 8 m.

Clause 6.6.1.6 Each lintel required by clause 6.6.1.5 to be secured against uplift shall in addition to the fixing required by Appendix A be fixed at each end to a trimming stud which is fixed to floor framing, each fixing to be as shown in Figure 41 or an alternative fixing of 5 kN capacity in tension along the line of the trimming stud.

Purlins

Clause 10.6.6 Purlins shall be fixed in accordance with the following recommendations:

(a) Where purlins are laid directly over sheet sarking or ceiling lining material of maximum 13 mm thickness, the fixing of the purlin to the rafter shall be as given in (c) where:
   (i) In high wind areas the supporting area (purlin spacing times rafter spacing) of roof cladding exceeds 0.6 m^2.
   (ii) In medium wind areas the supported area exceeds 0.9 m^2.
   (iii) In low wind areas the supported area exceeds 1.2 m^2.

In all other cases the maximum fixing shall be two 100 mm x 3.75 mm skew driven nails.

(b) Where dummy rafters are laid over sheet sarking or ceiling lining material of maximum 13 mm thickness, the fixing of the purlin to the dummy rafter shall be in accordance with Table 30 (for fixing purlin to rafter) …

(c) Where required by clauses 10.6.6 (a) or (b) the fixing of the purlin or dummy rafter to a rafter shall be made using a length of 25 mm x 1 mm steel strip which is fixed to the rafter and purlin or dummy rafter as detailed in Figure 59B1 or 59B2, or an alternative fixing having a capacity of 2 kN. Such fixings may be spaced no further than 1.2 m apart.

Appendix A. Nailing Schedule

Rafter to ridge board	75 x 3.15 or	4 (skewed)
	100 x 3.75	2 (end nailed)
Rafter to top plate	Mix of skewed 100 x 3.75 nails only and nails plus wire dogs depending on situation (Note that the situations are slightly different from those in the 1978 version)	2 (skewed)
Underpurlins and underpurlin struts	Mix of skewed 100 x 3.75 nails only and nails plus wire dogs depending on situation	2 (skewed) 2 wire dogs
Purlins to rafters	Light roofs Range from 1 – 100 x 3.75 nail to 2 – 100 x 3.75 skewed nails plus one wire dog Heavy roofs 400 mm x 900 mm area – 100 x 3.75 1200 mm x 900 mm area – 100 x 3.75 25 mm thick purlins 400 mm x 480 mm area – 75 x 3.15 FH	1 to 2 (skewed) 1 2 (skewed) 1

NZS 3604:1990 Code of Practice for LIGHT TIMBER FRAME BUILDINGS not requiring specific design.

As for NZS 3604:1984 with some modifications and additions as follows:

Wind zones:

Clause 2.6.2 The wind zone (low, medium, high or very high) for each specific building site shall be determined from Table 2.4 by consideration of the wind region, the ground roughness and topography surrounding the proposed site, and the exposure of the proposed building on the site.

Low – 32 m/s
Medium – 37 m/s
High – 44 m/s
Very high – 50 m/s

Lintels

Clause 6.6.1.5 Lintels supporting rafters or trusses of light roofs shall be secured against uplift in accordance with clause 6.6.1.6 where:

(a) Very high wind exposure:
  (i) The roof dimension S exceeds 4.5 m; or
  (ii) The lintel span exceeds 2.0 m and the roof dimension S exceeds 4 m;
(b) High wind exposure:
  (i) The roof dimension S exceeds 6 m; or
  (ii) The lintel span exceeds 2.4 m and the roof dimension S exceeds 4 m;
(c) Medium wind exposure: The lintel span exceeds 2.7 m and the roof dimension S exceeds 8 m.

Clause 6.6.1.6 Each lintel required by clause 6.6.1.5 to be secured against uplift shall in addition to the fixing required by Appendix A be fixed at each end to a trimming stud which is fixed to floor framing, each fixing to be as shown in Figure 6.8 or an alternative fixing of 5 kN capacity in tension along the line of the trimming stud.

Figure 10.13 Purlin fixings for sarked roofs.

Fixing requirements for dummy rafters now related to wind zone.

Table A1. Nailing Schedule

Rafter or jack rafter to top plate or underpurlin (a) Light roof in very high wind exposure when: (i) The rafter span exceeds 2.5 m, or (ii) The rafter spacing exceeds 900 mm	100 x 3.75 plus cyclone tie with capacity of 16 kN	2 (skewed)
Purlins to rafters – light roofs – very high wind (a) 1200 mm x 1200 mm (b) 900 mm x 900 mm	100 x 3.75 plus wire dogs	2 (skewed) 1 2

NZS 3604:1999 TIMBER FRAMED BUILDINGS

Wind zone calculation unchanged from 1990 version. Wind bracing demands unchanged from 1990 version.

Lintels

Clause 8.6.1.7 Lintels supporting rafters or trusses of roofs shall be secured against uplift where indicated in Table 8.14. Where fixing to resist uplift is not required, the fixings of Table 8.19 for "*lintel to trimming stud*" shall be used.
Table 8.14 gives provides lintels spans for wind zones and contributing weight (loaded dimension) for which specific fixing types are required.

Clause 8.6.1.8 Each lintel required by Table 8.14 to be secured against uplift shall be fixed at each end to a trimming stud which in turn shall be fixed to the floor framing. Each fixing to be as shown in Figure 8.12, or an alternative fixing of 7.5 kN capacity in tension along the line of the trimming stud.

Table 8.19 gives:

Lintel to trimming stud	75 x 3.15 or 100 x 3.75	4 (skewed) 2 (end nailed)

Rafters

Clause 10.2.1.3.2 Rafter and valley rafter dimensions and fixing types shall be as given by Table 10.2 (see Table 15.6 for snow loads).

Fixing types are classified as:

Fixing type	Fixing to resist uplift	Alternate fixing capacity (kN)
A	2/100 x 3.75 skewed nails	0.7
B	2/100 x 3.75 skewed nails + 1 wire dog	2.7
C	2/100 x 3.75 skewed nails + 2 wire dogs	4.7
D	2/100 x 3.75 skewed nails + 3 wire dogs	6.7

Clause 10.2.1.5.2 The ridge beam shall be secured to the wall with a fixing type determined from Table 10.6. The fixing shall be as required by Table 10.3 and shown by Figure 10.7. The built up studs shown in Figure 10.7 shall be provided with base connections as required by Table 10.3 …

Table 10.3. Key to fixing types to restrain beam uplift

Fixing type	Fixing to resist uplift		Alternative fixing capacity (kN)
	Base connection of built up studs	Ridge beam to built up studs	
A	2/100 x 3.75 skew nails into bottom plate	2/100 x 3.75 nails	0.7
B	4/100 x 3.75 skew nails into bottom plate	4/100 x 3.75 nails	2.7
C	6/100 x 3.75 skew nails into bottom plate	6/100 x 3.75 nails	4.7
D	25 x 1 strap with 6 nails to stud and plate	1/M12 bolt	6.7
E	2/25 x 1 strap with 6 nails to stud and plate. 12 nails total	1/M12 bolt	8.7
F	3/25 x 1 strap with 6 nails to stud and plate. 18 nails total	2/M16 bolts	18.6

Underpurlins

Clause 10.2.1.9.1 The sizes of underpurlins and the fixings to their supports shall be as given in Table 10.6.

Fixing types in Table 10.6 are as follows:

Fixing type	Fixing to resist uplift	Alternative fixing capacity

		(kN)
A	2/100 x 3.75 skew nails	0.7
B	2/100 x 3.75 skew nails + 1 wire dog	2.7
C	2/100 x 3.75 skew nails + 2 wire dogs	4.7
D	2/100 x 3.75 skew nails + 3 wire dogs	6.7
E	2/100 x 3.75 skew nails + 4 wire dogs	8.7
F	2/100 x 3.75 skew nails + U strap of 27 mm x 1.2 mm 10/30 x 315 nails at each end	16.0

Verandah beams

Whole new section on spans for verandah beams and end fixing requirements.

Purlins and tile battens

Clause 10.2.1.16.1 The size of purlins and battens shall be taken from Table 10.9 using spacing to suit the spanning capability of the cladding. Fixings shall be selected from Table 10.10 to have a capacity equal to or greater than that required by Table 10.9.

Fixing types in Table 10.10 are as follows:

Fixing description	Fixing capacity (kN)
1/100 x 3.75 nail or 1/90 x 3.15 power driven nail	0. 4
2/100 x 3.75 skewed nails or 2/90 x 3.15 power driven nails	0.7
2/100 x 3.75 skew nails + 1 wire dog or 2/100 x 3.75 skewed nails + 1/14 g Type 17 screw to AS 3566	2.7
2/100 x 3.75 skew nails + 2 wire dogs or 2/100 x 3.75 skewed nails + 2/14 g Type 17 screw to AS 3566	4.7

Trusses

Clause 10.2.2.6 Anchorage
The fixing for a roof truss at its support shall be as given by the truss design, but not less than that required in Tables 10.12 and 10.13 and Figure 10.21.

Fixing types in Table 10.12 are the same as in Table 10.6 above.

APPENDIX B: RETROFIT SELECTION TABLE

House age	Design wind area	Current Wind Zone	Proposed Retrofits Purlin fixing (light roofs only)	Rafter fixing (light roofs only)	Truss fixing (for light roofs only)
Pre 1978	None specified	Low	Do nothing	Do nothing	No trusses
		Medium	Do nothing	Do nothing	No trusses
		High	Add single Z nail to purlin/rafter connection in periphery areas if rafter is Radiata Pine or Douglas Fir	Do nothing	No trusses
		Very high		Add "L" bracket between the rafter and plate, nailed (4) and screwed (2) in place .	No trusses
1978-1990	Low	Low		Add "L" bracket between the rafter and plate, nailed (4) and screwed (2) in place when contributing area to connection is 1.5 m^2 to 2.0 m^2.	Do nothing
		Medium		Add "L" bracket between the rafter and plate, nailed (4) and screwed (2) in place when contributing area to connection is 1.0 m^2 to 2.0 m^2.	Do nothing
		High		Add "L" bracket between the rafter and plate, nailed (4) and screwed (2) in place when contributing area to connection is up to 2.0 m^2.	For trusses spanning more than 7.6 m add "L" brackets between the truss and plate, nailed (8) and screwed (2) in place unless fixings are already stronger than 2 skewed nails and two wire dogs.
		Very high	Add single Z nail to purlin/rafter connection in periphery areas	Add "L" bracket between the rafter and plate, nailed (4) and screwed (2) in place when contributing area to connection is up to 2.0 m^2.	For trusses spanning more than 5.2 m add "L" brackets between the truss and plate, nailed (8) and screwed (2) in place unless fixings are already stronger than 2 skewed nails and two wire dogs.
	Medium	Low		Do nothing	Do nothing
		Medium		Add "L" bracket between the rafter and plate, nailed (4) and screwed (2) in place when contributing area to connection is 1.0 m^2 to 2.3 m^2 and if there are no wire dogs already in place.	Do nothing
		High		Add "L" bracket between the rafter and plate, nailed (4) and screwed (2) in place when contributing area to connection is 0.7 m^2 to 2.3 m^2 and if there are no wire dogs already in place.	For trusses spanning more than 7.6 m add "L" brackets between the truss and plate, nailed (8) and screwed (2) in place unless fixings are already stronger than 2 skewed nails and two wire dogs.
		Very high	Add single Z nail to purlin/rafter connection in periphery areas	When the contributing area is greater than 3.2 m^2 and nails and wire dogs are already in place, add "L" bracket between rafter and plate. When the contributing area is 0.5 m2 to 3.2 m2 and no wire dogs are in place, add "L" bracket between rafter and plate.	For trusses spanning more than 5.2 m add "L" brackets between the truss and plate, nailed (8) and screwed (2)in place unless fixings are already stronger than 2 skewed nails and two wire dogs.
	High	Low		Do nothing	Do nothing
		Medium		Add "L" bracket between the rafter and plate, nailed (4) and screwed (2) in place when contributing area to connection is 2.7 m^2 to 3.7 m^2 and if there are no wire dogs already in place.	Do nothing
		High		Add "L" bracket between the rafter and plate, nailed (4) and screwed (2) in place when contributing area to connection is 1.8 m^2 to 3.7 m^2 and if there are no wire dogs already in place.	For trusses spanning more than 7.6 m add "L" brackets between the truss and plate, nailed (8) and screwed (2) in place unless fixings are already stronger than 2 skewed nails and two wire dogs.
		Very high	Add single Z nail to purlin/rafter connection in periphery areas	Add "L" bracket between the rafter and plate, nailed (4) and screwed (2) in place when contributing area to connection is greater than 3.25 m^2 and if there are wire dogs already in place. Add "L" bracket between the rafter and plate, nailed (8) and screwed (4) in place when contributing area to connection is greater than 3.25 m2 and if there are NO wire dogs already in place. For contributing areas between 1.3 m^2 and 3.25 m^2, add "L" bracket between the rafter and plate, nailed (8) and screwed (4) in place.	For trusses spanning more than 5.2 m add "L" brackets between the truss and plate, nailed (8) and screwed (2) in place unless fixings are already stronger than 2 skewed nails and two wire dogs.
1990-1999	NA	Low	Add single Z nail to purlin/rafter connection in periphery areas when contrib. area is > 0.81m^2	Add "L" bracket between the rafter and plate, nailed (4) and screwed (2) in place when contributing area to connection is 1.5 m^2 to 2.0 m^2.	Do nothing
		Medium	Add single Z nail to purlin/rafter connection in periphery areas when contrib. area is > 0.54m^2	Add "L" bracket between the rafter and plate, nailed (4) and screwed (2) in place when contributing area to connection is 1.0 m^2 to 2.3 m^2 and if there are no wire dogs already in place.	Do nothing
		High	Add single Z nail to purlin/rafter connection in periphery areas when contrib. area is > 0.54m^2	Add "L" bracket between the rafter and plate, nailed (4) and screwed (2) in place when contributing area to connection is 1.8 m^2 to 3.7 m^2 and if there are no wire dogs already in place.	For trusses spanning more than 7.6 m add "L" brackets between the truss and plate, nailed (8) and screwed (2) in place unless fixings are already stronger than 2 skewed nails and two wire dogs.
		Very high	Add single Z nail to purlin/rafter connection in periphery areas when contrib. area is > 0.54m^2	Add "L" bracket between the rafter and plate, nailed (4) and screwed (2) in place when contributing area to connection is 0.5 m^2 to 3.7 m^2 and if there is no cyclone tie already in place.	For trusses spanning more than 5.2 m add "L" brackets between the truss and plate, nailed (8) and screwed (2) in place unless fixings are already stronger than 2 skewed nails and two wire dogs.
1999 onwards	NA	Low	Do nothing	Do nothing	Do nothing
		Medium	Do nothing	Do nothing	Do nothing
		High	Do nothing	Do nothing	Do nothing
		Very high	Do nothing	Do nothing	Do nothing