BUILDING FOR CYCLONES

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Ways and Means of preventing cyclone damage to buildings in the South Western Pacific

This booklet was written by Stuart W. Thomson (1929-2015), long recognised as a leading expert on metal cladding and roofing and cyclone resistant design. Known in New Zealand as the grandfather of roofing, Stuart was a businessman, development engineer, lecturer, consultant, adventurer, author and humanitarian who devoted much time in his later years to assisting Rotary International projects in the Pacific. He was a long-time member of the Rotary Club of Pakuranga and the Club acknowledges the support of Stuart's family in facilitating this republication.

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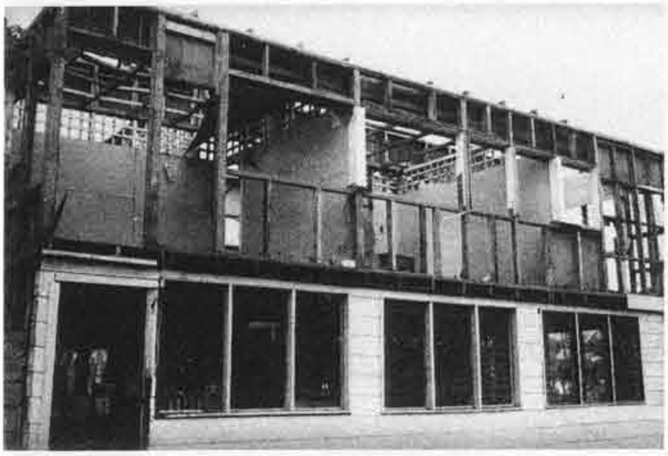
DISCLAIMER

WHY DAMAGE OCCURS

Severe cyclone damage to buildings in the Pacific occurs with such regularity that there is an obvious problem to be addressed. Although the international community provides help to assist those affected by the cyclone, unfortunately the methods often used to repair buildings are inadequate to resist the next cyclone. Sometimes a fatalistic attitude and expediency has allowed repairs using salvaged materials to repeat the same mistakes and often no attempt has been made to repair obvious faulty joints. It calls into question the usefulness of the type of repairs often provided through the generosity of overseas service organizations and public appeals.

The correct materials are often not available to effectively repair and upgrade cyclone-damaged buildings and there is a lack of knowledge of cyclone resistant building principles. A different approach is needed to rebuild or repair buildings than to build them, as a retrofit must be able to be accomplished without demolishing the building. This booklet does not advocate the use of proprietary metal connectors or nail plates except metal strapping as this material can be used in most instances to provide a simple but suitable joint. Also the use of wire can enable most joints to be upgraded. Local builders and relief builders coming from "non cyclone regions" such as New Zealand also need to understand the additional construction and fixing techniques that are necessary to hold down roofs against cyclone uplift wind forces. This booklet sets out to remedy this situation.



This booklet does not cover every aspect of building design but specifically targets those weak areas in the roof structure that initiate, or have caused failure in the past. It is hoped by its use that the standard of traditional building practice will be enhanced or at least some of the ideas presented may be used to prevent damage in the future.

It does not purport to be a Building Standard as they are generally written so that the man in the street cannot understand them. It does provide a hands-on graphic low-key approach explaining reasons that hopefully can be understood by the villagers as well as urban designers. It is a cookbook of recipes, some of them radical, but it outlines the basic principles and components needed to effectively design and upgrade buildings. It is intended for designers with structural knowledge, students seeking it, and for homeowners without it. Some on site supervision and inspection is also needed to achieve this goal.

For those who do not wish to calculate the wind forces, upgrading or rebuilding can be carried out by using the pictorial explanations, however a designer may, by following the calculations, specifically use the information to protect property and people from cyclones.

The writer has written and compiled this data and has been involved with cyclone resistant building design, product testing, building Standards and building in Fiji and Samoa for the last two decades, but to make a complicated subject simple and yet remain meaningful and user-friendly, is a difficult task.

The traditional approach to the construction of houses and some school buildings in the Pacific region relies on habit without the necessary structural engineering assessment required for cyclone design. As the Pacific is a cyclone prone area, appropriate action must be taken in the design of new and the repair of existing buildings to avoid repeating the devastation like that seen in the Labasa area after Cyclone Ami during January 2003.

The science of Wind Engineering has come a long way in the last two decades, but although the 'ultimate' cyclone resistant building is likely to be out of reach either because of financial or educational constraints, safety can be obtained by following the advice contained in this booklet.

A cyclone is a mass of air rapidly circulating clockwise around a low-pressure system about 20km in diameter. This centre is known as the eye. Most cyclones travel about 20km/h but can stall. When the eye is directly above, the air is an eerie calm before the turbulence reoccurs.

A severe cyclone scale 3 has winds gusting to 60m/s, (216 kph or 144 mph) a very severe cyclone scale 4 has winds gusting to 75m/s and a catastrophic cyclone scale 5 has winds gusting to 90m/s. A very severe cyclone force can be 50% greater than a severe cyclone and as the force of the wind varies with the square of the velocity, the potential for a major disaster is ever present.

The wind speeds referred to are those taken at a height of 10m at a very exposed site and therefore require modification depending on where the building site is situated.

WHY DAMAGE OCCURS *continued*

Fiji has averaged over one severe cyclone a year for the last 100 years. Sometimes there have been three cyclones in one year and sometimes none at all have affected the Fiji Islands.

For those who have lived through a cyclone, it is an experience that they will never forget. At this time people are traumatized and therefore all precautions must be in place well before any cyclone warning is given.

Observations during and after cyclones, including much documented evidence has shown that catastrophic disintegration seldom occurs. Failure usually starts from a roof overhang or gable end and creates an instant domino effect that appears to be catastrophic. Although a roof may appear to 'explode', failure will have initiated at a single joint.

Incremental failure of fastenings is the major cause of ultimate failure and it is important that analysis of the mode of failure does not confuse the result and the cause. The sequence of failure often places a load upon the fastener or the connection that it was not designed for i.e. roofing sheets that start to peel from the barge, act as a lever to pull an adjacent fastener out. Torsional loading of eccentric fastenings or those requiring a large or impractical number of nails offer resistance far below their claimed or expected performance.

PROBLEMS

An analysis of the mode of building failure in cyclones has led to some interesting but disturbing conclusions.

The first is that except for Cyclone Val that devastated the North-western areas of Savaii in 1991, most of the recent Pacific cyclones have not been greater than a severe cyclone scale 3 with winds gusting to 60m/s. There are many buildings still now standing in the affected areas of both Fiji and Samoa that could not have withstood a wind force in excess of 55 m/s.

The second disturbing observation is that people become complacent and often rely on a few concrete blocks to hold their roof on. Fortunately there has been little loss of life with recent cyclones. Because of better warning systems, because cyclones very often come during the Christmas school holidays and because they have come at night, people have avoided lethal metal roofing and building debris. Storm surge, coupled with high tides and the torrential rain that accompanies cyclones and causes flooding, have and will continue to claim lives.

The third observation is that there are obvious omissions of good trade practice which contribute to building failure or cyclone damage.

Problems

- *No, or inadequate rafter ties allows rafters to lift off the top plate*
- *The use of undersized timber members,*
- *The use of smooth shank nails in tension,*
- *The absence of strap or wire ties,*
- *The use of simple rafter construction on wide buildings,*
- *Verandahs too wide and not tied adequately*
- *The reliance solely on skew nailing*
- *The re-use of damaged materials*
- *No, or inadequate purlin ties allows large portions of roofs to "hinge".*
- *Excessive eave dimension causes roof and often building damage.*
- *Lack of nails and washers allows metal roof cladding to 'pull-over' and lift off the purlins.*
- *Secret fix roof claddings are not suitable for cyclonic conditions unless they are top fixed.*
- *No roof barge flashings on gable end buildings and peripheral failure allows roof to peel*
- *Barge flashings without vertical fastening, sufficient vertical height or an adequate number of fasteners.*
- *No attic ventilation. To reduce positive pressure, a gable apex vent should be fitted*
- *Use of top plates on concrete block walls.*
- *Use of birds-mouthing of rafters*
- *Reliance on weatherboards to supply bracing.*
- *Gable buildings used in preference to hipped roofs.*
- *Ineffective owner efforts to restrain the roof by wire or concrete blocks.*

Any building has a multiplicity of joints and wind induced stress will find the weakest link in the chain. It is necessary to have a balanced package, as there is little point in strengthening one part of the building without strengthening other parts. The potential of metal roofing and horizontal cladding as a bracing element or stressed skin diaphram has not been recognised.

The three very vulnerable areas are:

- *Verandahs and overhangs*
- *The rafter to top plate connections*
- *The edge of a gable end roof.*

Damage can be avoided by ensuring that:

- *Any extended rafters are braced into a triangle*
- *Additional ties are made from the rafter to the stud*
- *Add flashings nailed on both the vertical and horizontal surfaces.*
- *Use screws and washers instead of nails around the outside edges of the roof.*

There are many simple and inexpensive changes which must be given consideration that can substantially alter a building from being a potential disaster to a save haven in a storm.

The use of:

- *'Stressed skin' design*
- *Wired joints*
- *Buttressed panels*
- *Triangulated connections*
- *'Cut-in' purlins*
- *Saddle straps*
- *Cyclone tension strapping*
- *Roof truss construction*
- *Repositioning and reducing the number of dominant openings*

UNDERSTANDING FORCES

How does a building stay together under high wind loads?

Fortunately wind is dynamic and the maximum calculated design load does not arrive at the same time and at the same place, so the load is shared by other components of the building after a time lapse referred to as the response time or period.

These few seconds are important where materials working within their elastic capabilities can move but do not permanently yield. If any component is loose, this movement can lead to fatigue at a load much lower than the maximum design load. There is some counter balancing of wind forces but gusting initiates damage that can quickly escalate particularly around the corners and edges of the roof.

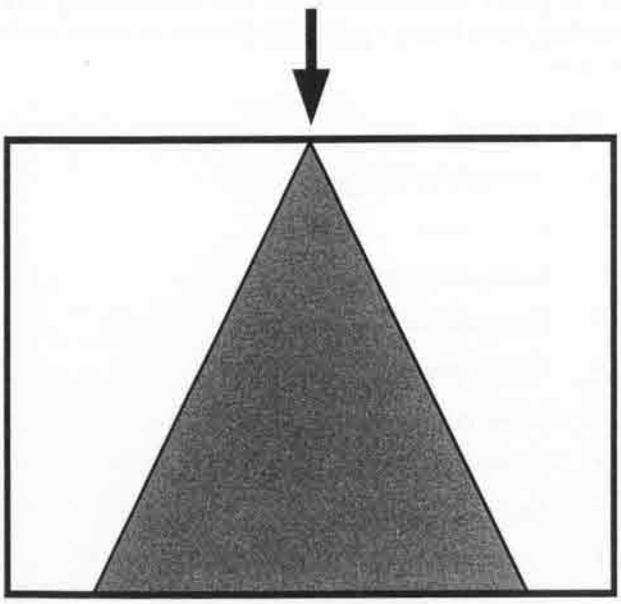
Wind is turbulent and accelerates around obstructions and buildings, although the terrain, topography and the height above ground are often more important factors than the wind speed itself. Cyclone damage is the combination of all these factors coupled with building design that is not capable of withstanding the wind load.

LOAD SHARING

One of the most important factors in spreading and sharing of the wind forces is the metal roof cladding. As described in 'Stressed skin' a roof or wall cladding shear diaphragm provides bracing to the whole building. When a building loses its roof sheeting, the bracing effect of connected steel sheets is gone and often contributes very quickly to the total disintegration of the building.

Tests on stressed skin roofs show that the shear stress per fastener is very low and elongation of roofing fastener holes is unlikely when load-spreading washers are used.

Load sharing is recognised as being present even though it cannot be easily quantified and the use of stressed skin, triangulation, and wide sheeting materials all add considerably to the stability of the structure. Evidence from structures damaged by cyclones confirms that the load intensity diminishes as it is carried to the ground and very seldom is a building completely destroyed to the foundations. The load sharing could be illustrated by a triangle.



The type, gauge and length of nail used in building is more one of local habit rather than design, however the number, position and type determine whether the building will stand up in the next cyclone. Smooth shank nails must not be used to nail metal roof cladding.

The integrity of the builder and the surveillance of the owner are required if performance standards are to be met.

Nail and screw holding power depends on several factors:

- *depth of fastener penetration*
- *diameter and type of shank – smooth, twisted, grooved, screwed.*
- *timber density*
- *the moisture content of the timber when driven*

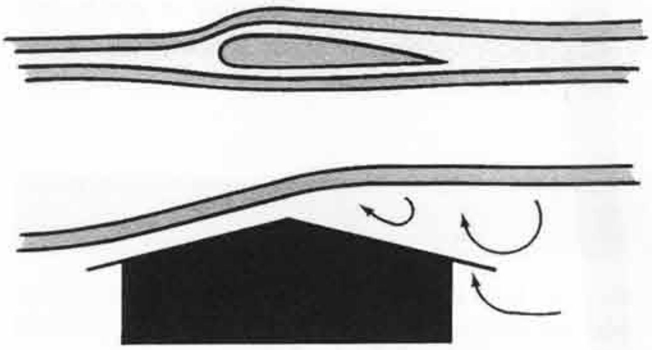
There is correlation to an extent between these factors, but as the of variation of test results is high the safety factor also becomes high, which means that the holding power of fasteners into timber is not an exact science.

The performance of a twisted shank nail falls between that of a smooth and spiral shank nail. N.B. Some springhead nails are twisted shank and some are not. Smooth shank nail timber joint connections are not capable of resisting cyclonic tension loads at the rafter/top plate, or purlin/rafter joints, and they must have additional resistance added in the form of a metal saddle, strap or wired joint. There simply is not enough room to put sufficient smooth shank nails in these joints to hold the roof down in a cyclone. In simple rafter construction, without ceiling or wall linings or partitions, the external walls and the roof cladding have to provide the total racking strength to the building.

WIND LOAD

The force of the wind speed alone is not the wind design load as the wind speed must be multiplied by several factors to arrive at the load on any particular part of the building.

The wind load on a roof can be positive or negative but the most severe load is negative, suction or uplift load that is trying to lift the roof away from its fastenings or from the structure.



Just as an aircraft wing provides lift when the engine forces air over it, so does a cyclone try to lift the roof off the ground. This wind load is measured in kPa = kN/m^2. To provide an indication of this uplift, the force on the edge of the most exposed site would equal 7.0kPa which is approximately 700kgs for every square metre.

In the absence of any full scale cyclic load testing of buildings, wind design loads have to be based on static loads.

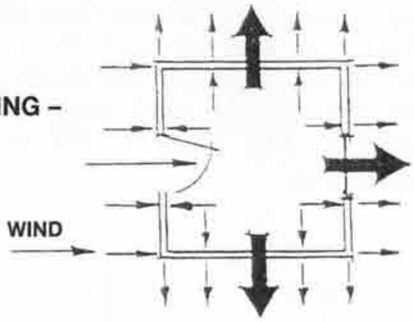
Wind design load on any building is influenced by the:

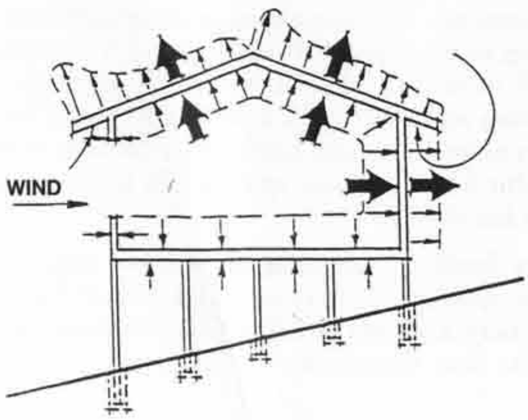
- *the effects of adjacent hills and valleys.*
- *the nature of the terrain*
- *building height,*
- *building proportions,*
- *orientation,*
- *roof pitch,*
- *the number of spans,*
- *windbreaks and obstructions*
- *dominant openings*

Openings in walls on the windward side of a building can lead to an increase in internal pressure thereby adding to the effect of external suction and subjecting cladding and fixings to higher tensile loads

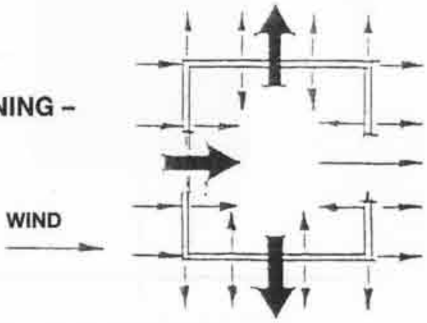
A chimney provides an automatic vent to equalize pressures but not all buildings now have chimneys.

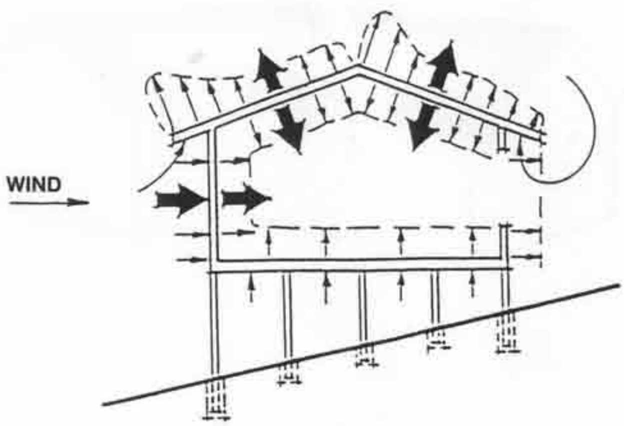
WINDWARD OPENING –
Internal Pressure





LEEWARD OPENING –
Internal Suction





PRESSURE COEFFICIENTS

Pressure coefficients are factors used to alter the wind design load on a building, and their values are dependent on the openings in the building and the pitch of the roof. A pressure coefficient providing full internal pressurization is recommended for specific design in cyclonic reasons, however this does add considerably to the design load.

Where there are large openings or there is a threat of flying debris, full internal pressurization should be calculated for building wind design load.

It is recognized that while shutters are a good theoretical method to prevent window damage from flying debris when there is a threat of a cyclone, they often cannot be found or else there is no one to erect them.

Eave and verandah roof cladding is subject to both external suction from above and positive pressures from underneath and to a greater degree when it is not lined.

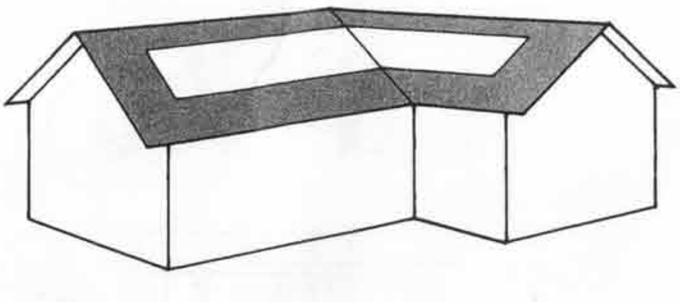
Any roof is vulnerable to damage whenever it is extended by a large overhang, verandah or porch, and the wall pressure coefficient must also be added to the negative pressure from above.

THE LOCAL PRESSURE COEFFICIENT

The periphery of roof and wall cladding has to withstand a greater uplift load than the main body of the roof and the purlin and/or rafter spacing must be reduced in these areas. The local pressure coefficient only applies to the roof sheeting and the connection of the purlin to the rafter.

Either additional fixings and/or load spreading washers are therefore required to provide additional support to the sheeting where the pullover capacity of the cladding is exceeded or where fatigue could lower the capacity of the sheeting. The factor local pressure coefficent which applies to the edges of all buildings is 1.5 at a dimension equal to 0.2 or 20% of the width or height of the building whichever is the least. The height of the roof is taken to be the average height from the ridge to the eave but this factor does not apply to the hips and ridges of roofs less than 10°.

Many buildings are designed without either reduced purlin spacings or an increased number of fixings at the periphery, and roof cladding failures almost universally initiate from these areas.



Because the load is increased by 50% at the periphery, by reducing the purlin and rafter spacing by 1/3 the load at the joint is equalized. L= load S = span

i.e.

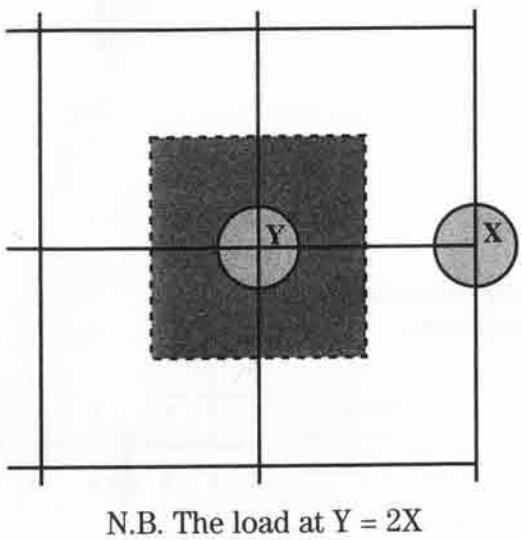
$L1 \times S1 = 1kN$

$L1 \times 1.5 = L2 = 1.5$

$S1 \times 2/3 = S2 = .667$

$L2 \times S2 = 1.5. \times .667 = 1$

The load on a connection or joint is shared by adjacent connections but must withstand its share which is dependent on the distance from other connections. To find out the load on a connection, multiply the span by the spacing to provide the effective area and multiply the result by the wind design load in kPa for the building. The result in kN is the load on the connection.



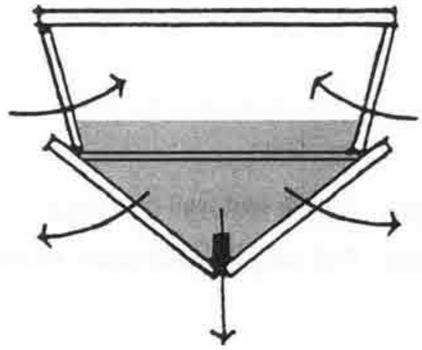
N.B. The load at Y = 2X

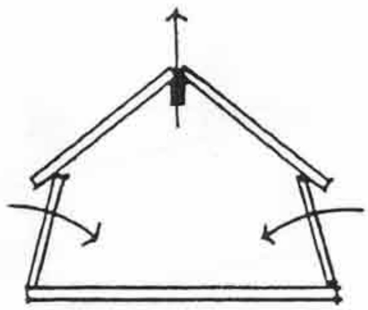
MODES OF FAILURE

It is helpful to think of a building as a suspended upturned boat filled half full of water.

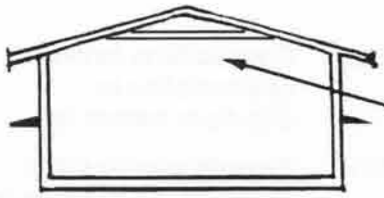
This represents the forces acting on each of the joints when under stress from a cyclone. A building 8m x 12m would be filled with over 100 tonnes of water and it is logical to think of the places that would 'burst' under this load.

The first member to suffer would be the keel or apex of the roof, and this is what often happens – the rafters part at the ridge board or ridge beam. The 'planking' the roof sheeting being very thin would belly between the fixings and without load spreading washers would 'burst' off the framing as does metal roofing.

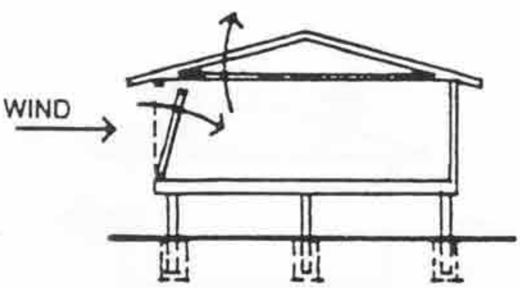




PROBLEM: Ridge not tied down and rafter/top plate Skew nailed

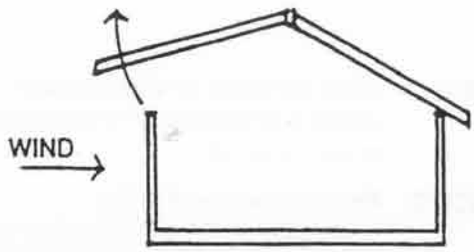


SOLUTION: Use collar ties and triangulate Stud rafter connection



PROBLEM: Walls blow in and Roof lifts

SOLUTION: Provide adequate fixing of top and bottom plate to studs

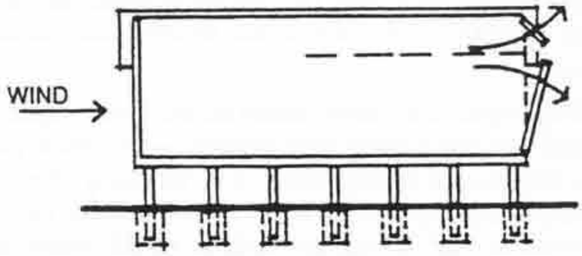


PROBLEM: Tie down of rafter to top plate inadequate for wind force

SOLUTION: Fix securely at top plate

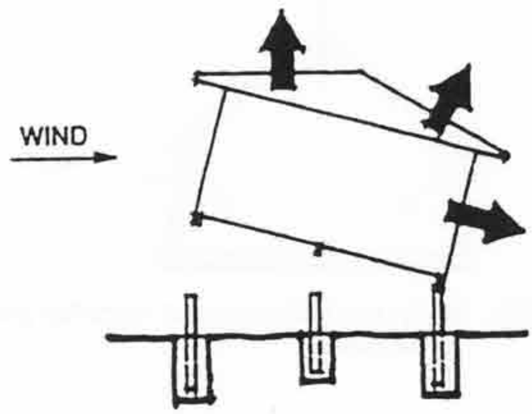
PROBLEM: Gable end wall blows out

SOLUTION: Full height Gable studs to roof



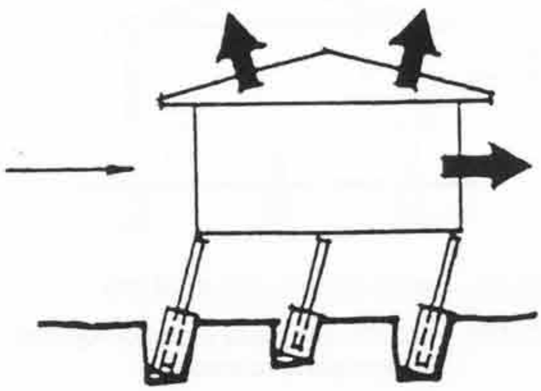
PROBLEM: Connections between bearers/piles or sub-floor frames fail.

SOLUTION: Provide wire or strap connections between bearers and piles and braces and piles.



PROBLEM: Piles not deep or wide enough to resist overturning or constructed in soft ground

SOLUTIONS: Provide deep and wide foundations. Piles exceeding 1.2m must be laterally supported with diagonal braces.



STRUCTURAL ELEMENTS

This booklet considers three main structural elements of building:

- ***A tie or cable***

  A tie or bar as it also called, is a straight tension member whereas a cable can be curved. They are very thin compared with their length.

- ***A strut***

  A strut is a straight compression member and is called a column or stud when it is used vertically. It will buckle or break if it is overloaded.

- ***A beam***

  A beam is a horizontal or angled member transferring vertical loads horizontally. Due to bending it can develop compression at the top and tension at the bottom. A rafter acts as a beam.

When under load all building elements react to equalise the force by three main mechanisms:

- *Tension*
- *Compression*
- *Shear*

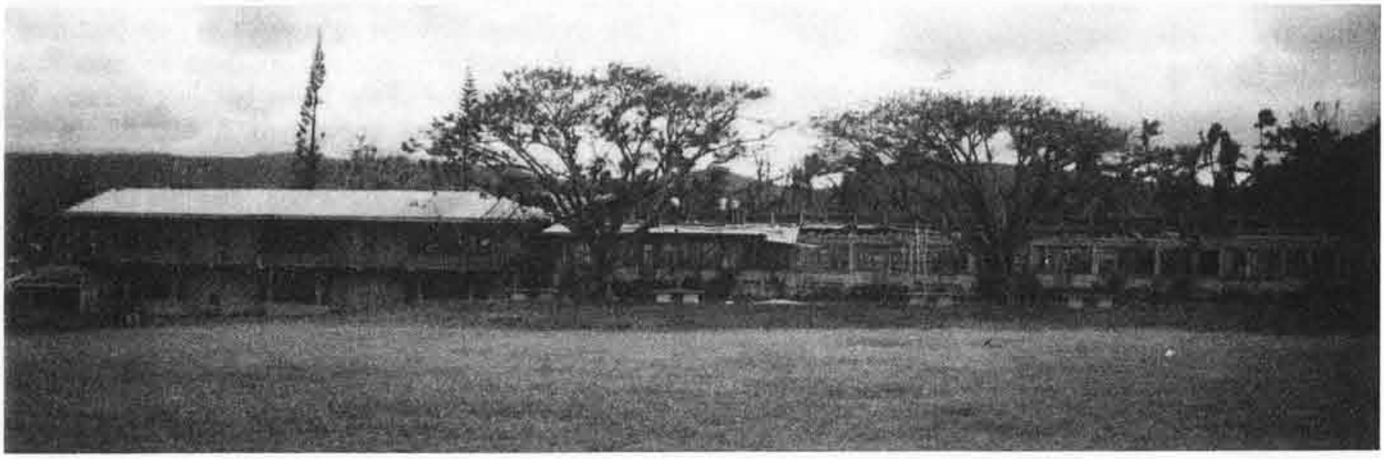
Not only do the structural elements suffer these forces, but the connections and the fasteners holding them together also must resist these loads.

A building under cyclonic conditions is subject to reversing or cyclic loading and this can induce fatigue in very thin materials such as steel particularly around roof fasteners.

TENSION (STRETCH)

COMPRESSION (SQUASH)

SHEAR (SLIDE)



FASTENER PERFORMANCE UNDER LOAD

As fasteners perform differently in tension and in shear, the performance of timber joints and the fastening of profiled metal cladding is dependent on the ability of the fastener to resist the tensile (pulling), and shear (sliding) forces imposed during a cyclone.

The strength of a connection is dependent on both parts of the joint:

- *the type of fastener*
- *the type of material it is fastened into.*

As fasteners perform better in shear loading than in tension, for uplift loads it is better to use nails, screws and bolts, horizontally (in shear) than vertically (in tension).

Timber is an organic material which means that it is not consistant. The values given in section 'Solutions' for joint performance are for any softwood timber similar to Fiji Pine.

Hardwoods will perform better than softwoods, but care must be taken not to split the timber and drilling could be necessary. End grain does not hold fasteners as well as side grain.

There are a number of factors that govern joint strength:

- *Wood density*
- *Moisture content when driven*
- *Moisture content when under load*
- *Type of nail or screw shank*
- *Wood grain direction*
- *Fastener eccentricity*

BUILDING STANDARDS

Although the requirements in this booklet are valid, it is not intended that they be used for those buildings for which specific design is required. (Class A buildings)

Class A

Very High/High Building importance category -

Hospitals, Fire Stations, Police Stations, Communications Centres and Safe haven shelters.

Specific design for schools, churches, commercial and industrial buildings and dwellings requiring cyclone insurance.

These buildings must be designed and certified by practicing structural engineers.

Class B

Medium Building importance category -

Dwellings, schools, commercial and industrial buildings not requiring specific design. Dwellings in village areas.

It is intended that the requirements in this booklet be used for all other buildings in cyclonic regions whether they have experienced a cyclone or not.

There has to be a measurable standard to which upgrading .is carried out, but following a cyclone expediency demands that schools be re-roofed, and that people return to their own homes. This is foremost in most people's minds, and quite rightly so. The problem is that availability of materials, money and knowledge is lacking at this time, which has the potential to create an even greater disaster in the future.

Without a benchmark there is no likelihood of the standard of building being raised. To insure a building against cyclone damage, the Insurance Company usually sets the standard but the commercial reality is that the builder will work to a price and not a standard.

55 m/s is considered a reasonable standard for the wind speed that must be resisted by a commercial, industrial building or a dwelling. Villagers who lead simple lives in simple dwellings have the right to know how best they can use the resources available to them to meet this standard. The nature of the house building industry is such that individual engineered house design is uneconomic but because houses account for over half the total of building construction, they are of greater social importance as they provide shelter and living facilities for people.

WIND LOAD CALCULATION

To calculate an accurate wind design speed for a specific building site is complex because of all the factors that need to be considered:

- *wind direction*
- *terrain*
- *building orientation*
- *ground topography*
- *elevation*
- *shielding*

It is possible however to determine a conservative wind design load for the roof and wall cladding for any building site by ignoring the direction of the wind and any shielding that may not be permanent by using the multipliers in the following method.

Limitations of this procedure are:

- *that it does not include buildings dedicated to the preservation of human life, or public buildings such as libraries or halls.*
- *It does not include buildings that exceed 10 metres in height, or are above 500m in elevation.*
- *The result must not be used as a design load until all other factors are used to appreciate or depreciate the wind load.*

When using this booklet it is not necessary for the owner, builder or designer to calculate the wind design load, but it is necessary to assess the exposure for an individual building to obtain the specific design requirements.

Two examples have been given with the same wind speed but with different exposure categories.

The loads can be interpolated when they lie between the two values for the two sites described S1 and S2.

The proximity or position on a hill must be determined as topography is the most important criteria.

Schools are often built on or near the crest of a hill and as they have large unbraced wall areas they fall into the most severe category

The wind forces that act on any part of a building are dependent on:

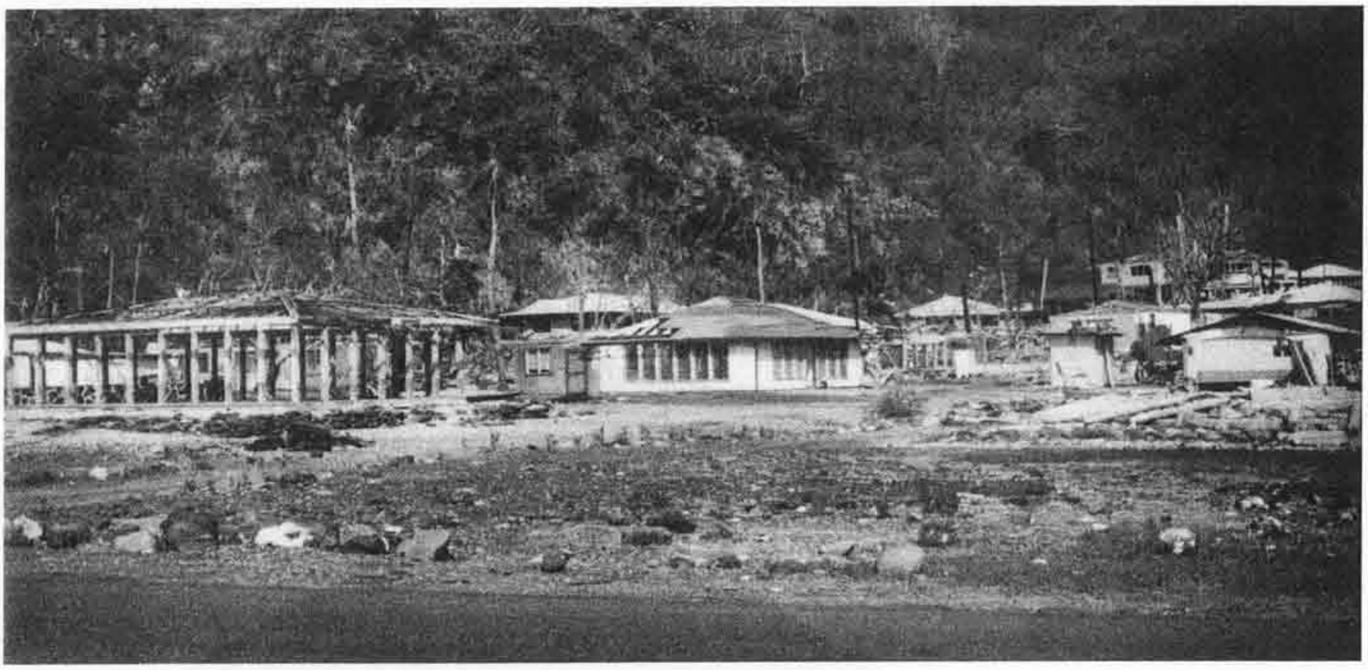
- *wind region*
- *terrain roughness*
- *topography*
- *pressure coefficients*

The site design wind load can be determined by assigning a value to each of these four variables individually and by multiplying them together.

N.B. the site design wind load should be determined before being modified by the pressure coefficients.

A five step simplified calculation is possible once information concerning the building and the site are known.

The multipliers are taken from AS/NZS 1170.2 2002.



EXAMPLES

Two examples of different building sites (S1 and S2) are given and used to show the influence of the terrain and the topography. Both sites have the same wind speed but have diferent terrain and topography.

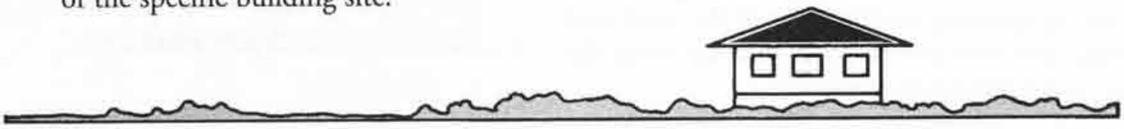
SITE 1 (S1)

STEP 1 **Determine the regional wind speed.** = 55m/s

STEP 2 **Determine the Terrain Multiplier**

The terrain multiplier is the classification of the terrain roughness or obstruction over which the wind passes before it reaches the building site and increases or reduces the wind speed. Any obstruction should have permanence and not rely on vegetation.

The multiplier should be selected on the basis of the category that most closely fits the description of the specific building site.



Open terrain, grassland or water surfaces with a few well-scattered obstructions between 1.5 – 10m high Typically farmland.

Multiplier =1.0 The Regional wind speed is multiplied by the applicable terrain multiplier.

STEP 3 **Determine the Topographic Hill Multiplier.**

The site wind speed is influenced by the topography of the land that will affect the wind flow in the vicinity of the building site, however if a hill peak is more than ten times its height away from the site any influence may be ignored. The most critical areas are those near the top of a hill, cliff or escarpment, and valleys which are subject to accelerated wind flow due to the convergence of the surrounding hills. Any assessment of the effects of topography on the wind design load is indicative only as topography is three dimensional, and the evaluation is two-dimensional. It therefore is not possible to cover all situations and a subjective judgement is necessary.

The following assessment and calculation of the Topographic Hill Multiplier is valid only for topography where the hill slope is less than 24°.and because wind direction has been ignored the result will be conservative.

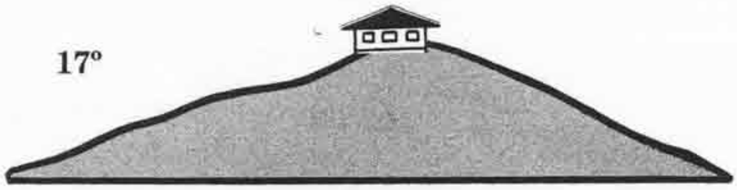
The Topographic Hill Multiplier is determined by the slope of the hill and the distance that the building is away from the crest.

Site 1 is either: **(a) on the top of a 17° slope. (a rise of 1 in 3.25)**

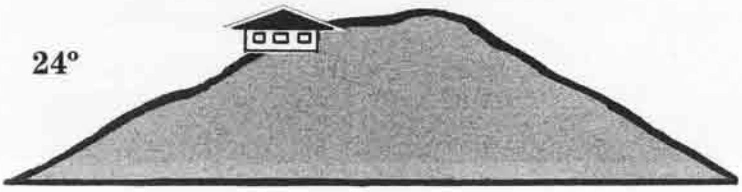
(b) 2/3rds the way up on a 24° slope. (a rise of 1 in 2.25)

Multiplier = 1.47

A



B



STEP 4 **Determine the Site Wind Speed** Using AS/NZS 1170:2002

Multiply Regional Wind Speed x Terrain Hill Multiplier x Topographic Hill Multiplier.

= 55 x 1.00 x 1.47

Wind design speed (V) = 81 m/s

Determine Roof Design Load

Wind design load = $0.6V^2 \times 10^{-3}$ kPa

= 3.94kPa

STEP 5 **Determine the Pressure Coefficients (Pc) applicable to the roof or wall cladding and the purlin connection.**

For buildings with dominant openings or permeable walls, and permanent roof ventilation equal to the area of the largest dominant opening

Pc = 1.2

Multiplier is = 1.2

Roof design load = 3.94kPa x 1.2

= 4.72kPa

Local Pc (x 1.5) = 7.08kPa

SITE 2 (S2)

STEP 1 **Determine the regional wind speed.**

= 55m/s

STEP 2 **Determine the Terrain Multiplier.**

The Regional wind speed is multiplied by the applicable terrain multiplier.

Terrain

The terrain multiplier is the classification of the terrain roughness or obstruction over which the wind passes before it reaches the building site and increases or reduces the wind speed. Any obstruction should have permanence and not rely on vegetation.

The multiplier should be selected on the basis of the category that most closely fits the description of the specific building site.

Multiplier is = .87

STEP 3 **Determine the Topographic Hill Multiplier.**

Topographic Classification

SITES ON FLAT LAND OR UNDULATING HILLS LESS THAN 3°. (1: 20)

Multiplier is = 1.

This multiplier does not apply where the building site is on the flat area beyond a hill, cliff or escarpment when the building site is within a distance of equal to ten times the height of a hill.

STEP 4 **Determine the Site Wind Speed** Using AS/NZS 1170:2002

Multiply Regional Wind Speed x Terrain Hill Multiplier x Topographic Hill Multiplier.

= 55 x .87 x 1.00

Wind design speed = 48m/s

Determine Roof Design Load

Wind design load = $.6V^2$

= 1.38kPa

STEP 5 **Determine the Pressure Coefficients applicable to the roof or wall cladding.**

For buildings h/w = or < 0.5, with dominant openings or permeable walls and permanent roof ventilation equal to the area of the largest dominant opening

Pc = 1.2

Multiplier is = 1.2

Roof design load = 1.38 x 1.2 = 1.66kPa

Local Pc(kl) x 1.5 = 2.49kPa

There is a large difference in the design wind load on a building on Site 1 compared with Site 2 due to the topography and the terrain, notwithstanding that the same wind speed is used. Although the buildings on S1 and S2 are the same size, the rafters and purlin spacing should be very different because of the different wind load on each building.

When assessing individual buildings it is likely that the wind design load will fall between the two values of the examples shown.

However although the wind load is proportional to the square of the wind speed, the design wind load is not proportional and it is prudent to design schools for the worst conditions when they are on a hill or are surrounded by open fields.

For lessor width buildings in the same areas with the same wind load, the rafter connection load can be proportionately adjusted.

The uplift load on any connection is dependent on the area the it services. This area is determined by the span and spacing of the connected members and their position on the roof or wall.

The uplift load must be taken firstly by the roof cladding and its fasteners, followed by the purlin connection, next to the rafter connection and ultimately to the ground.

In the case of a verandah post connection, the strength of the base detail must equal that of the post/ beam connection. In the case of a wall the load at the base can be assumed to be shared.

SOLUTIONS

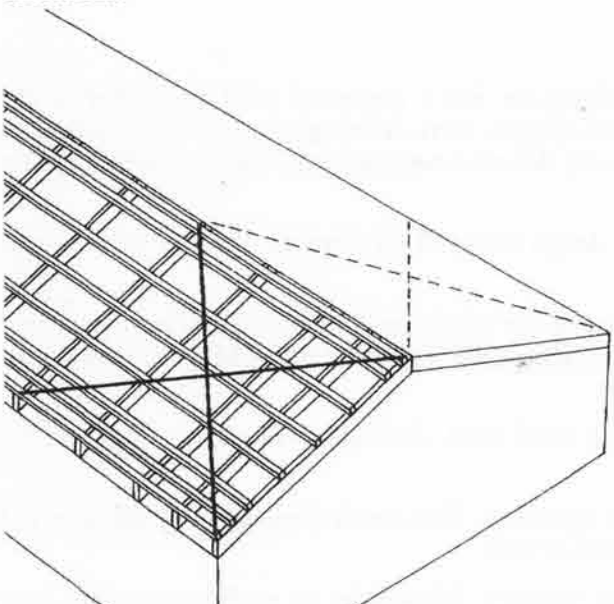
TRIANGULATION

Triangulation is the basis of all bracing and therefore must be understood in order for the bracing to work efficiently. The simplest rigid shape a structure can have is a pinned triangle. This basic geometric shape acts most efficently as a brace at 45°, although it can still provide bracing at different angles.

There are two types of braces:

- *Tension*
- *Compression*

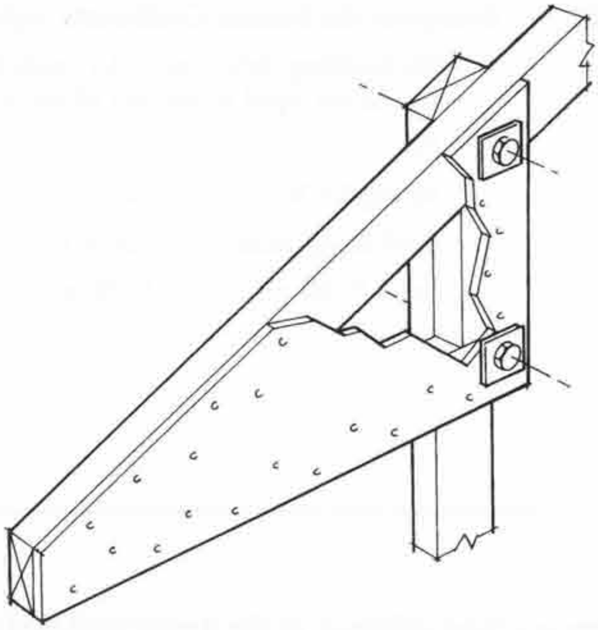
Steel is strong in tension but weak in compression therefore whenever a metal strap brace is used there must be two tension braces acting in opposite directions.



When timber is used as a brace it can act both in compression and in tension.

Both of these braces rely on the connection to the structure by nails or screws which must be sufficient in number and size to resist the racking forces.

Trusses use triangulation as the means of spanning large distances without deflecting or sagging and are a more efficient way to use timber rather than by rafters. Trusses, are the prefered roof structure in cyclone areas and must be used over 10m spans. Their important connections are made by nail plates on both sides of the intesecting joints. When rafters are used they can be strenghtened by the use of a cleat and/or a collar tie which can additionally be 'filled in' to the apex by rigid



material such as plywood, fibrecement board or even metal roof cladding. In addition the two rafters at the apex must be strapped together across the top using six nails per side. (see page 21)

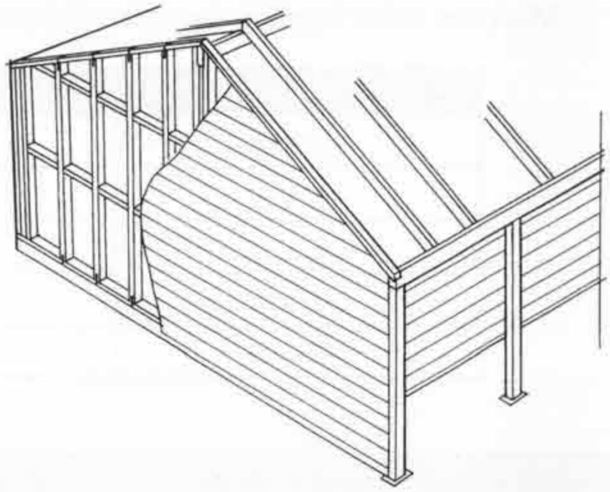
In the diagram above, the rafter and horizontal soffit member are bolted to the stud which provides triangulation and rigidity to the stud/rafter joint.

Plywood or other rigid material can be used to fill in the triangle to the stud which will increase the rigidity of the connections. In very exposed areas all overhangs must be triangulated.

BUTTRESSES

A butress is a supporting wall that extends outside the building as a bracing support for the roof and wall structure. It is a simple and economic way of providing stability to an otherwise unstable building. It not only provides strength by triangulation but it also holds down the rafter when there is insufficient joint capacity at this connection. Depending on the width of the verandah or eave and the length of the rafter, the rafter connection is subject to between five and ten times the load of the purlin./rafter connection.

When concrete block construction is used the buttress wall is required to give stability to any long unsupported wall such as a schoolroom.

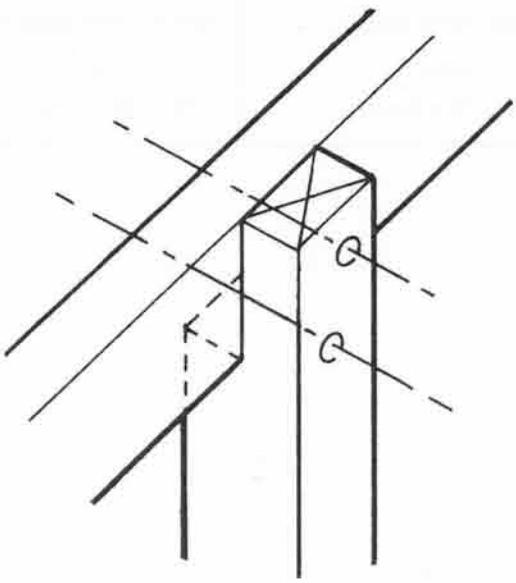


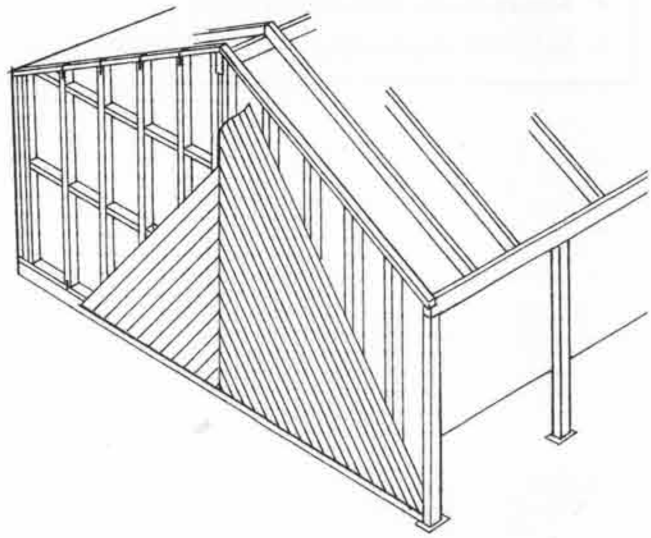
GABLE ENDS

Gable ends must have full height studs and trusses must not be used at the gable end.

When a raking top plate is used the nails are in tension but if the gable end studs are checked out for the end rafter, the nails perform better because they are in shear. This is the preferred method as it does not require the metal straps that are required for a top plate.

All gable ends with verandahs must have the verandah end 'filled in' by full length horizontal metal cladding and included as a buttress wall. The wall cladding must be fixed to the bottom plate and preferably to the floor joists and bearers. Where an opening is required a gable end it must be in the middle and not at the ends. If weatherboards are to be used on the gable ends they should be fixed at an angle of 45°





Flying purlins should not be used in cyclonic areas at the gable end because they produce a large loading on the connection which is often the point of initial failure for the roof structure. If an overhang is required it must be triangulated back to the studs in the manner shown.

FRAMING

Maximum Rafter length in metres for a light weight /metal roof (20kgs/m^2) wind design load = 55m/s

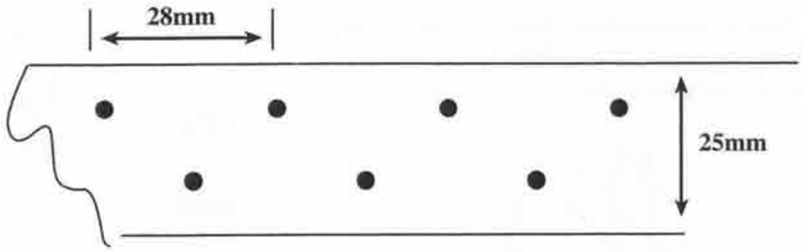
Nominal size in mm	600mm spacing	900 mm spacing
100 x 50	2.5	2.1
150 x 50	3.5	3.1
200 x 50	4.1	3.4
250 x 50	4.6	3.8
300 x 50	5.0	4.1

DESIGN

Minimum criteria design in exposed cyclone areas	S1 (or schools)	S2
• Maximum rafter length	5.0m	5.0m
• Maximum rafter spacing	600mm	900mm
• Maximum overhang	400mm	600mm
• Maximum overhang with verandah posts	2.0m	2.0m
• Maximum rafter spacing at periphery	400mm	600mm
• Overhang at gable end	Nil	Nil
• Maximum purlin spacing	900mm	900mm
• Maximum purlin spacing at periphery	400mm	600mm
• Trussed roof construction required over	5.0m	5.0m
• Maximum size bolt through 50mm timber	12mm M12 (1/2")	10mm M10 (3/8")
• Maximum size holes for M12 bolts	14mm	12mm
• M12 bolts require square washer each side	50 x 50 x 3mm	50 x 50 x 3mm

METAL STRAPS

The performance of metal straps is dependent on the number of nails used to fasten them in shear. Because often an impractical number are required, metal straps must be wrapped around at least through 2/90° bends which will reduce the shear force substantially. Straps that are not wrapped around must have a minimum of 6 nails per side of the strap. Galvanised steel strapping must be a minimum of 25mm wide and have a minimum thickness of 0.95mm.



WIRED JOINTS

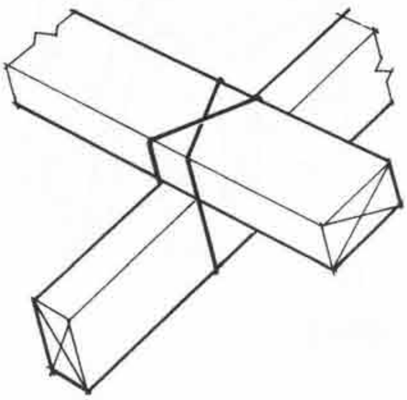
Wired joints offer a cheap alternative to proprietary fixings. Wire must be 'soft' that is it must not be high tensile so that it can be carefully hammered into shape around the joint. Wired joints have the disadvantage that they must be tight and if they become loose after a cyclone they must be re-tensioned. Wire has the advantage over some alternatives that they can be easier to retrofit and can be 'wrapped around' to improve the holding capacity.

Tests on 4.00mm, 3.00mm, and 2.5mm, m.s. galvanized wire showed that joint failure in the heavier gauges of wire occurred prematurely because the wire pulled through the fastener before the wire ultimate breaking load was achieved. Staples or U nails proved an inadequate fastening in all cases and must not be used.

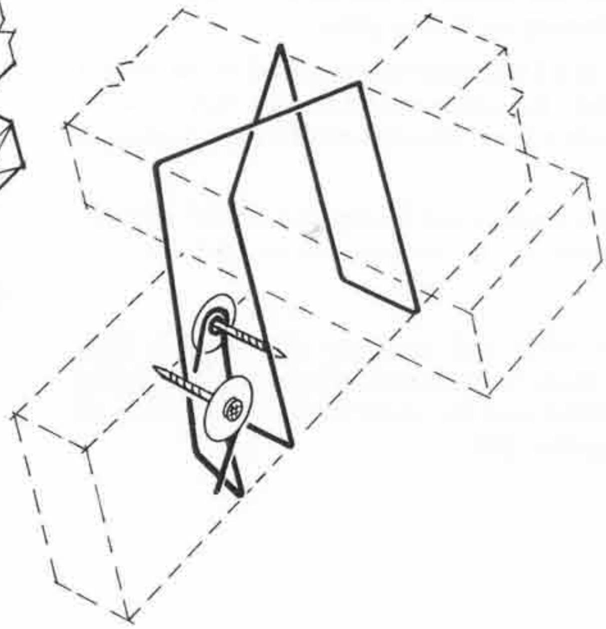
The lighter 2.5 mm wire (12#) is easier to use and must be fixed using a 60mm spiral shank roofing nail and washer on one side of the timber and winding the wire completely around it once, then taking it under the timber before crossing the wire over as shown in the following drawing. The other end of the wire is treated similarly. The nail must be driven home after the wire has been tensioned, and must be a spiral shank roofing nail with a washer as other nails are inadequate Care must be taken not to "nick" the wire when tightening with pliers or vice-grips.

- ***Do not use a claw hammer, as it will cause premature failure by damaging the wire.***
- ***Wire must be taut. If it is not, it should be tightened by a wooden wedge.***

The wire can be doubled to provide double the strength. (CC6 =kN)



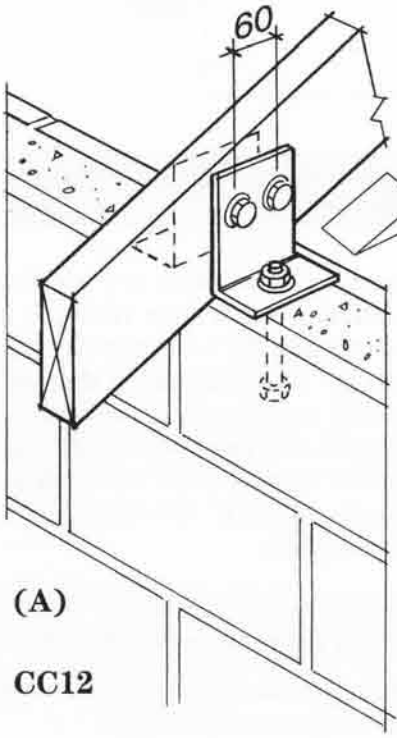
CC3



RAFTER/TOP PLATE

The rafter/top plate connection is very highly stressed and is often the initial failure point of the building.

The uplift load on the rafter/top plate connection is dependent on the width of the building but can be 5-10 times greater than that on an adjacent purlin. For this reason concrete block construction must not have a top plate but must have an angle or a saddle bracket to bolt the rafter or truss directly into the concrete. (A)



(A)

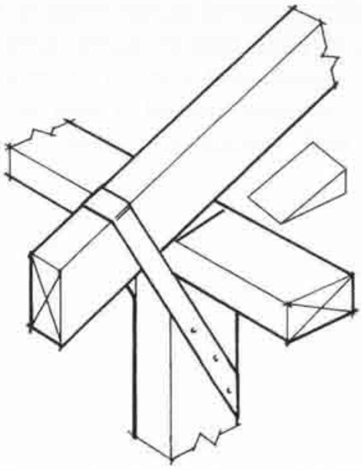
CC12

Where rafters attach to the top plate they must not be bird mouthed as this induces a weakness at this point where the most strength is required and a timber wedge must be cut and nailed to the rafter to provide full horizontal bearing on the top plate.

Because the wind load must be transferred to the ground where possible, the rafters should line up with the studs so that there is a direct line and no off centre loading at this point.

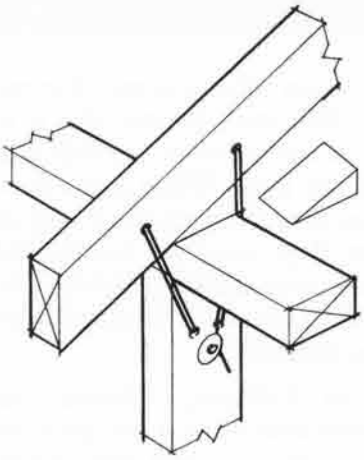
Metal straps or wire should wrap around and over the purlin/top plate and be fastened into the stud. (B) (C)

Where the rafter and stud do not line up their connection must be strengthened by using two timber members nailed into the studs as shown, and then all strapped together. (D)



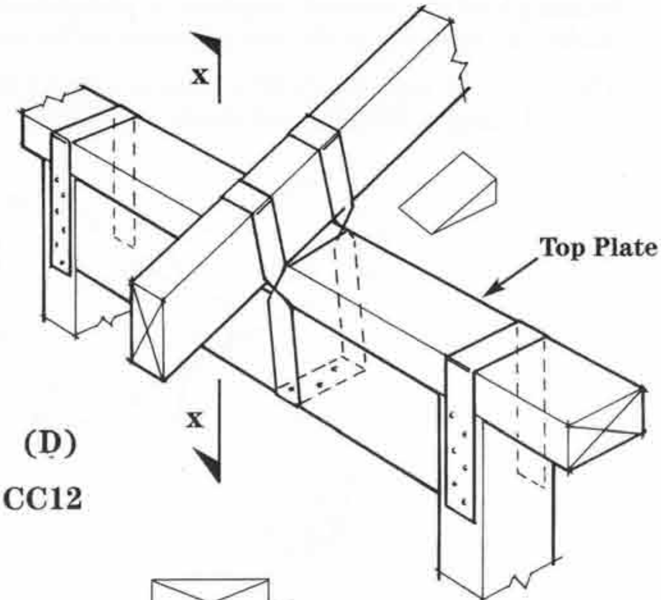
(B)

CC6



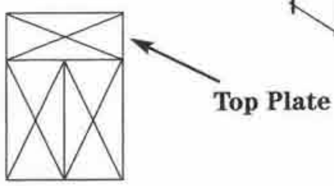
(C)

CC6



(D)

CC12



Section View of x-x

RIDGES

When using rafter construction there are several alternative ways to support rafters at the ridge.

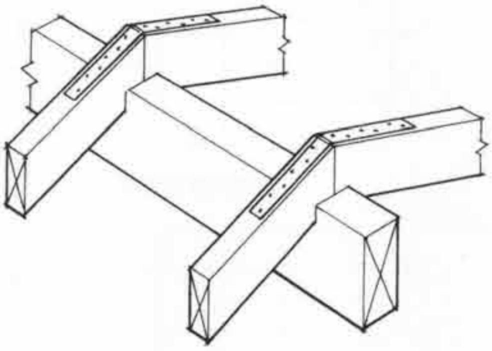
- Using a ridge board (A).
- Using a ridge beam to span between gable ends, a post or a load-bearing wall (B).

In all instances the two rafters must be bridged by

- *tension metal straps with a minimum of six nails per rafter (A) (B)*
- *a horizontal collar tie or cleat must be fastened as shown to triangulate the connection. (C)*
- *wire fastened or strapped and wrapped around as shown on drawing of wire joints. (page 19 and 20)*

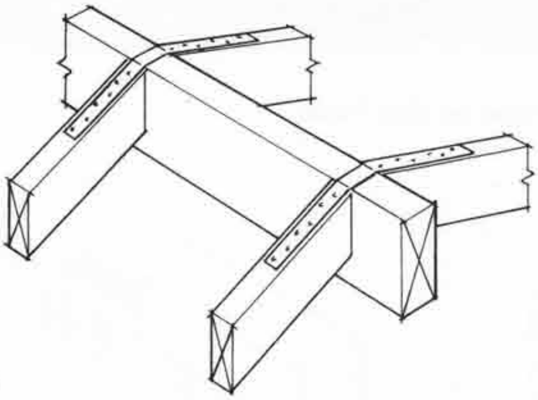
In very exposed areas the intermediate span rafters should have a collar tie, and also be clad up to the apex with rigid sheeting, plywood or corrugated metal cladding.

The verandah and the main roof must be the same pitch and the rafter must be in one length.



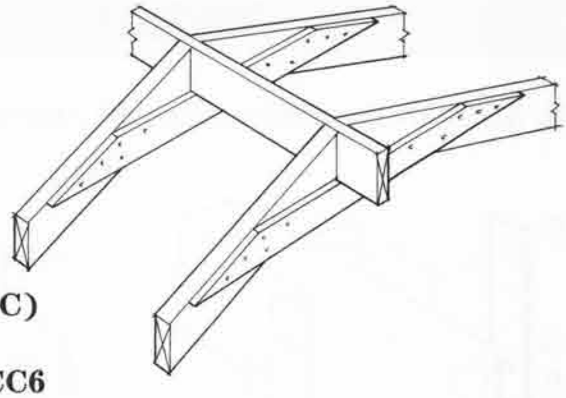
(B)

CC6



(A)

CC6

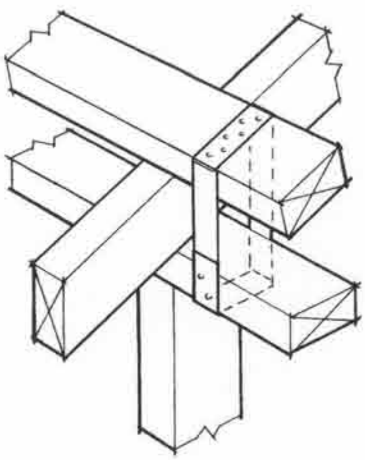


(C)

CC6

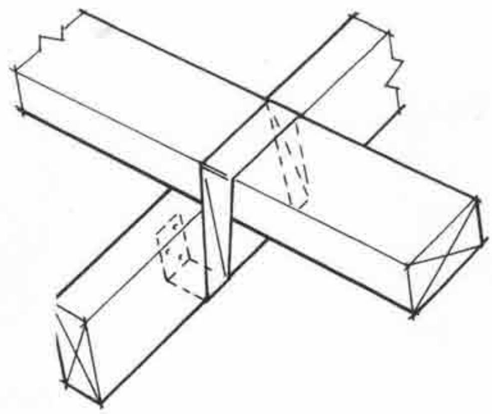
PURLINS/RAFTER

Where possible a purlin should be placed above the top plate so that this highly vulnerable joint can be strapped in the manner shown. In high wind load areas the connection requires two straps, one either side, or two wire joints providing eight verticals.



(A)

CC6

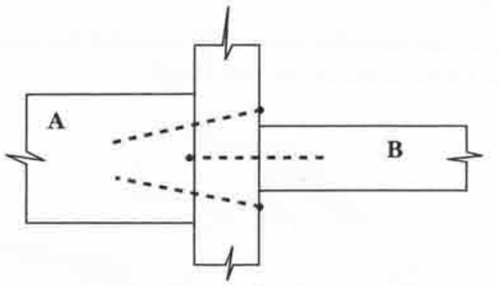


(B)

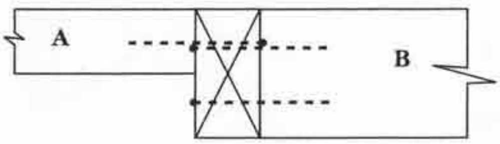
CC6

CUT-IN PURLINS

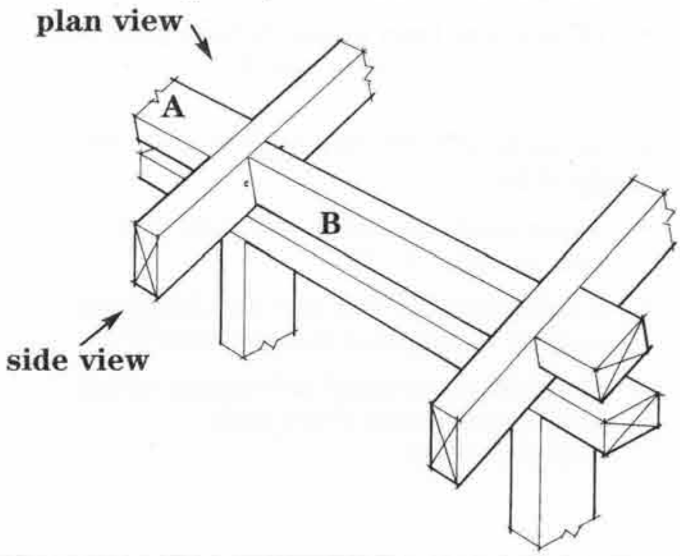
Purlins can be cut in between the rafters as shown to avoid purlin strapping and they can be fixed one across, one down, using two 100mm nails in each end of each purlin as shown. The purlin on edge should be fastened first and the purlin on the flat nailed subsequently.



plan view

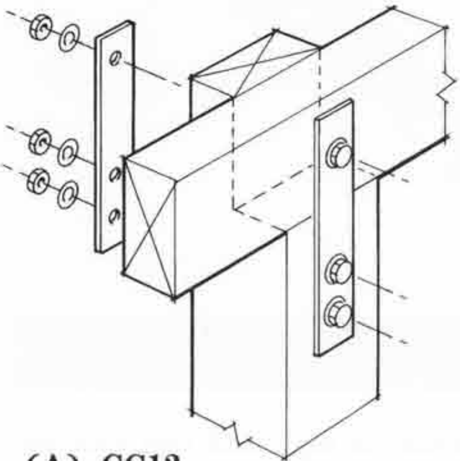


side view

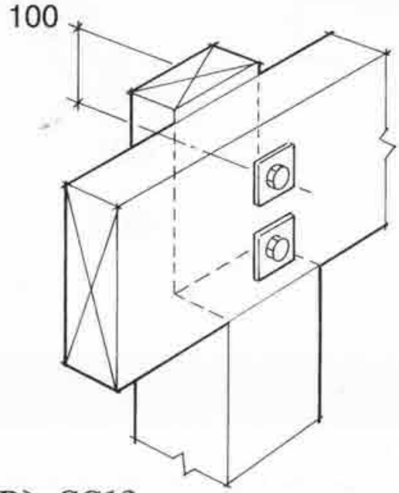


VERANDAHS POST/BEAM

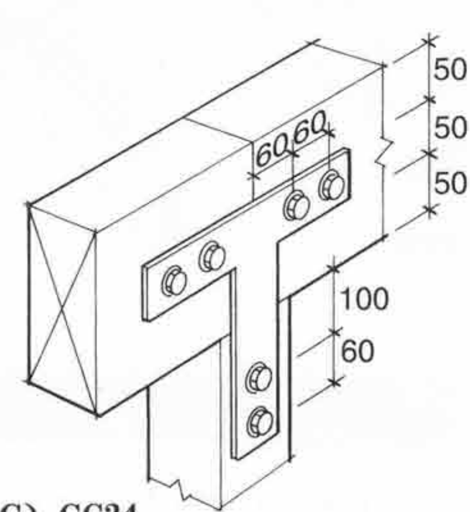
N.B. All posts must have an equal capacity connection at the base.



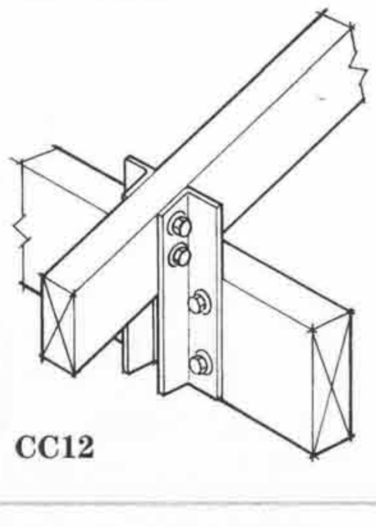
(A) CC12



(B) CC12



(C) CC24



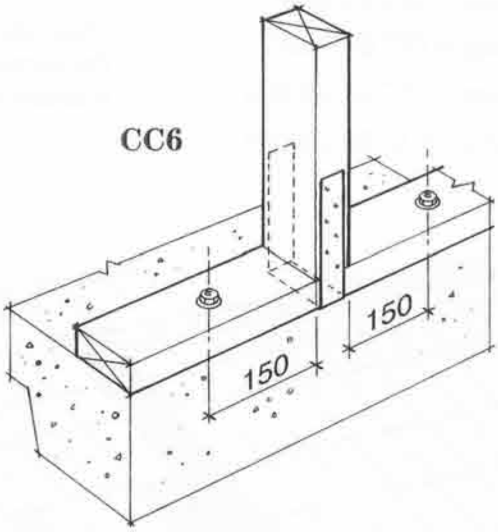
CC12

STUDS/BOTTOM PLATE

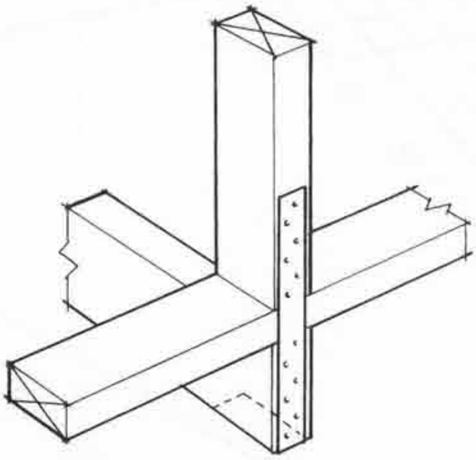
All studs must be strapped with a minimum of 12/ 3.0mm nails (6 each side of join)

Note: The top plate must be strapped to the studs in the same manner as shown for the bottom plate.

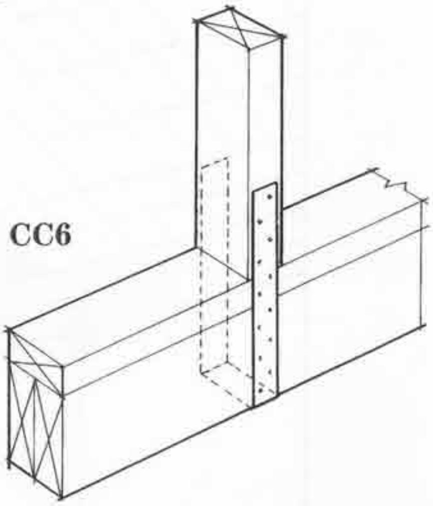
CC6

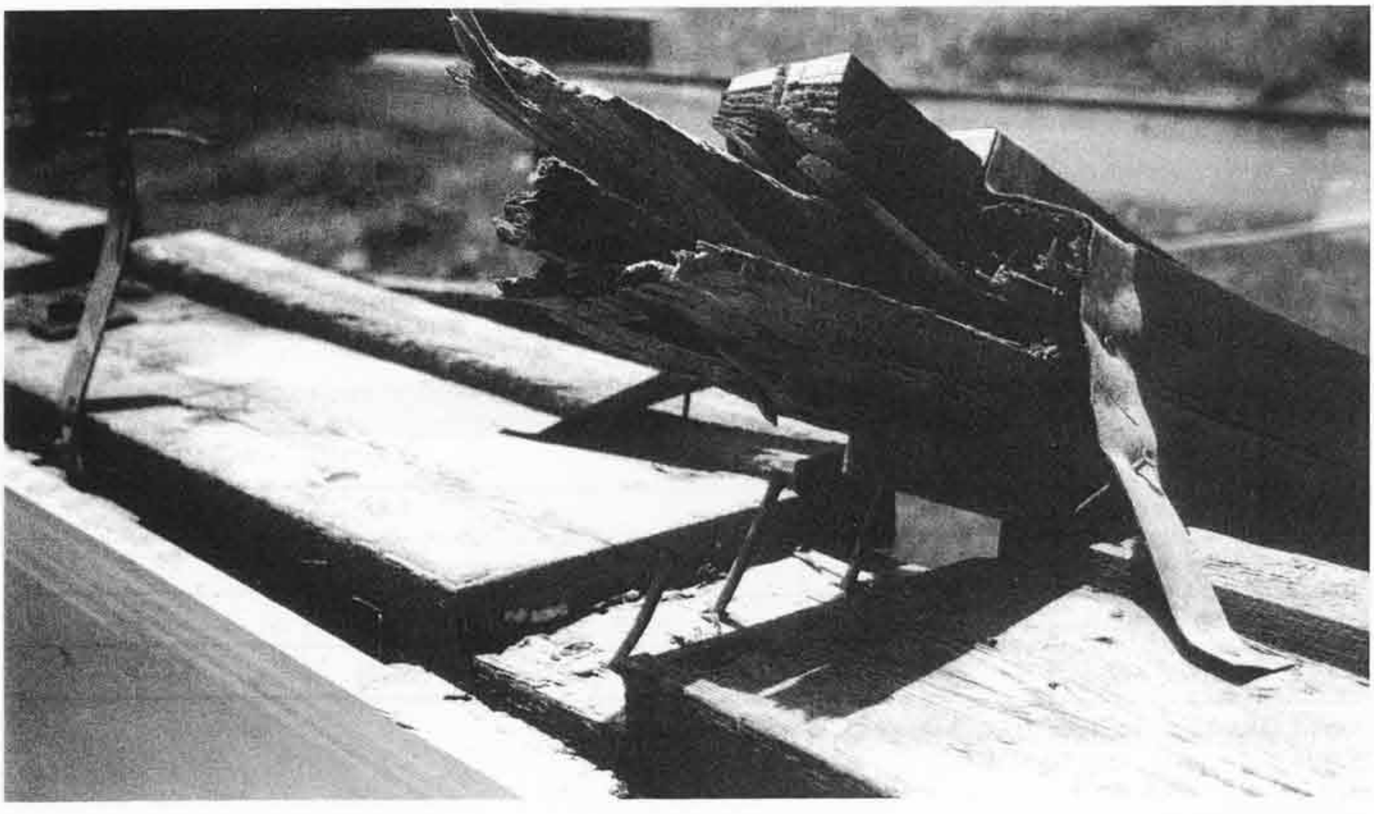


CC6



CC6





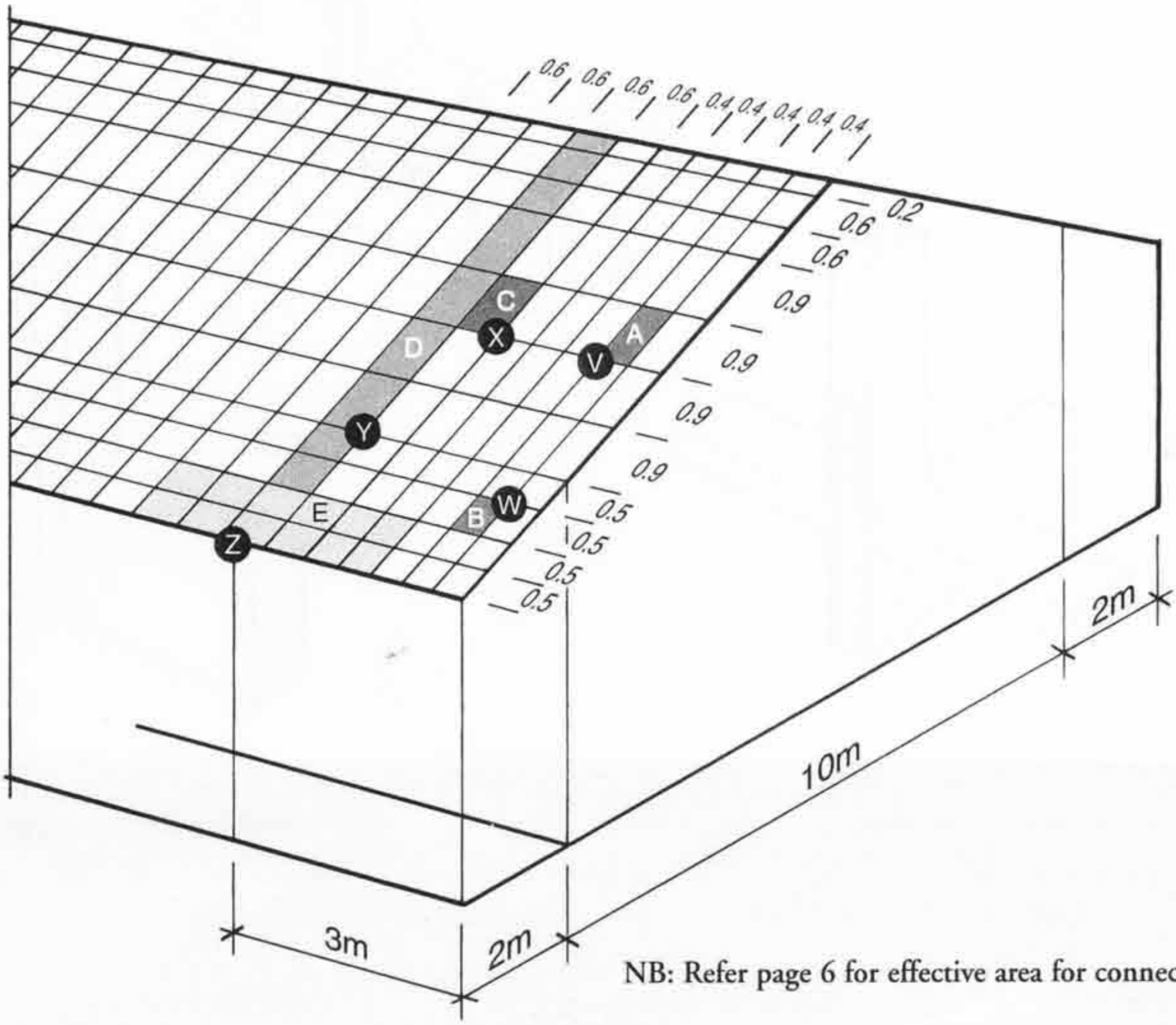
CONNECTIONS

To simplify the joint fixing options they have been divided into four groups.

- Connection Capacity = CC 3 = 3kN
- Connection Capacity = CC 6 = 6kN
- Connection Capacity = CC 12 = 12kN
- Connection Capacity = CC 24 = 24kN

Joint capacity is determined by how many nails/screws or bolts are in each connection and there must always be a minimum of 6 nails in each end of each strap.

Once the load has been established, the connection of the correct type and capacity can be selected from the illustrations.

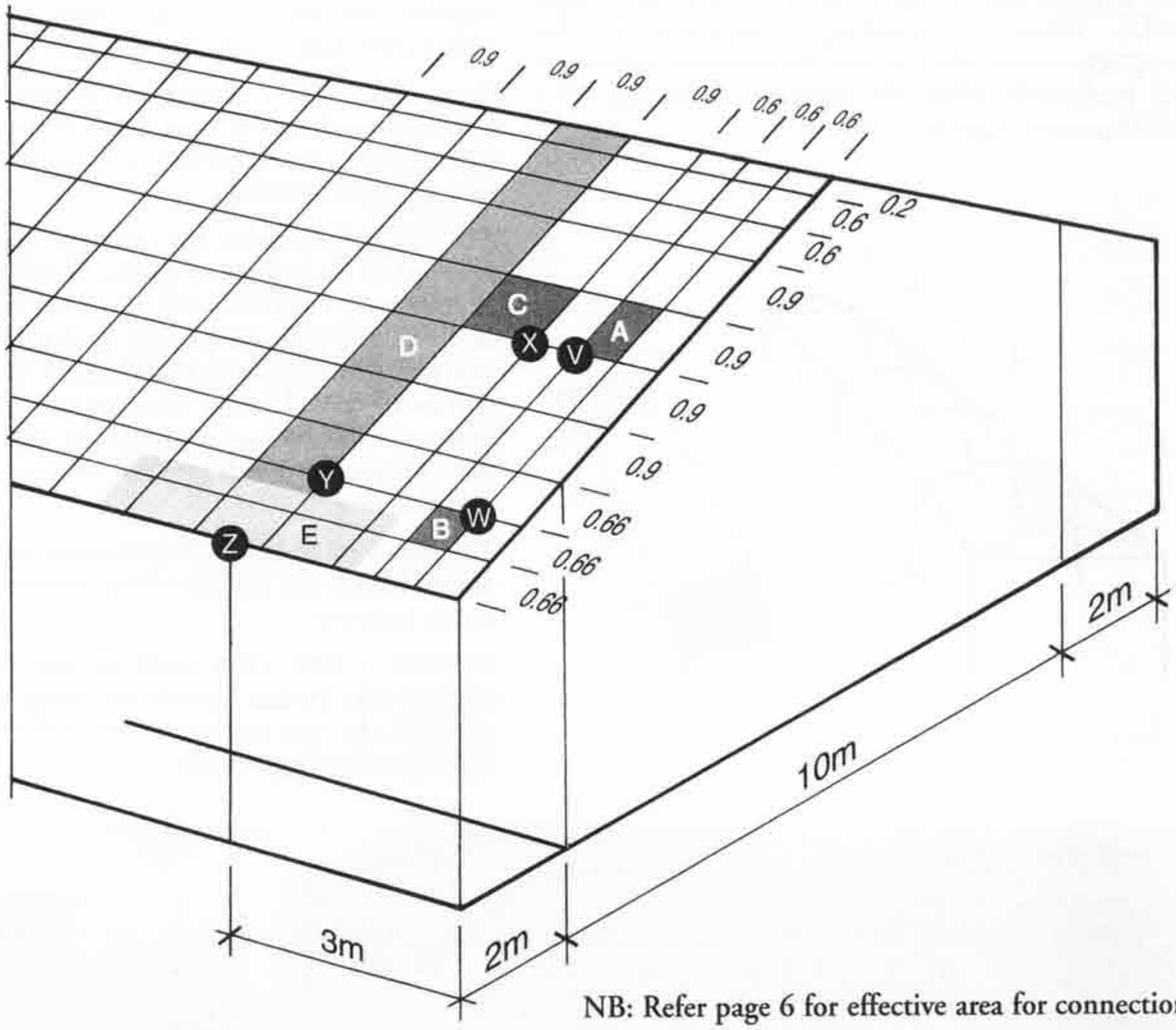


NB: Refer page 6 for effective area for connection.

SITE 1 (S1)

AREA		CONNECTION	DESIGN LOAD 4.72kPa	kl 7.08 kPa	TYPE OF FASTENING
A	.9 x .4 = .36	V =		2.15	CC 3
B	.5 x .4 = .2	W =		1.42	CC 3
C	.9 x .6 = .54	X =	2.15		CC 3
D*	6 x .6 = 3.6	Y =	17.0		CC 24
E	1 x 3 = 3	Z =		21.24	CC 24

* With ridge beam Reaction at Y is dependent on rigidity at the apex.



NB: Refer page 6 for effective area for connection.

SITE 2 (S2)

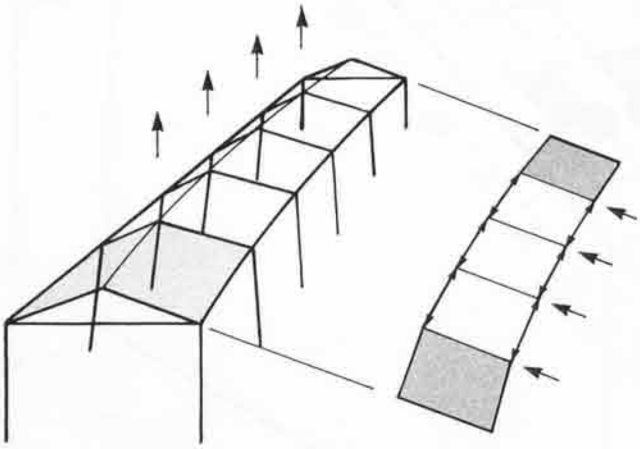
AREA		CONNECTION	DESIGN LOAD 1.66kPa	kl 2.49 kPa	TYPE OF FASTENING
A	.9 x .6 = .54	V =		1.35	CC 3
B	.6 x .66 = .4	W =		.99	CC 3
C	.9 x .9 = .81	X =	1.35		CC 3
D*	6 x 0 = .9	Y =	8.96		CC 12
E	1 x 3 = 3	Z =		7.47	CC 12

* With ridge beam Reaction at Y is dependent on rigidity at the apex.

STRESSED SKIN DESIGN

The use of high strength corrugated or trapezoidal steel roof and wall cladding adds considerable additional stiffening to the building.

Diaphragm action from the sheeting can be utilised to carry the wind loads that are applied to the frame by the sheeting, and this concept is called Stressed Skin Design (SSD). Whether a building is designed for this composite action effect or not, the sheeting interaction will profoundly affect the structural behaviour of a building under high wind loads.



When vertical uplift load is applied to the frames there is a tendency for the apexes to move upwards and the eaves to move inwards and this movement cannot take place without causing in-plane deflections of the roof sheeting. The sheeting has considerable in-plane stiffness and tends to resist this displacement by acting, together with the supporting purlins, in the manner of a deep plate girder spanning from gable to gable.

Stressed skin action provides the continuity to take the load back to the gable ends which are in turn stiffened by horizontal metal sheeting and eventually the load is taken to the foundation.

For this to take place the sheeting must be directly fastened to the purlins by means of self-drilling screws or nails which will not work loose, nor fail prematurely in shear, nor pull out causing tearing of the cladding material. Adjacent sheets must be side lap stitched if the purlins are spaced further than one metre apart. All such fasteners must be fixed through the ribs or troughs of the corrugations which precludes the use of clipped-on roof cladding.

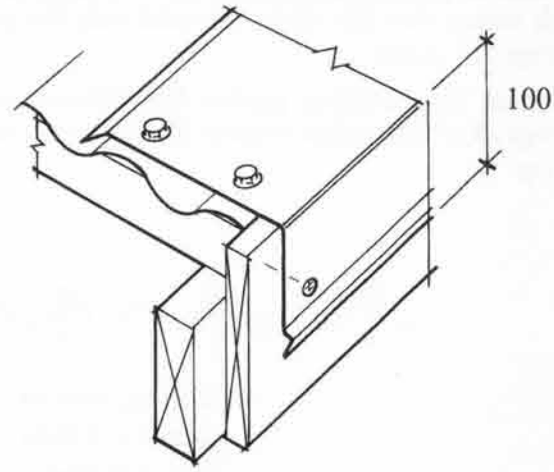
The periphery of all buildings requires a greater number of roof fixings and load spreading washers to avoid pull-out or pull-over.

As there is little extra work or cost involved using Stressed Skin Design because the fixings and details are standard, the cost savings are real and immediate over alternative bracing systems.

METAL FLASHINGS

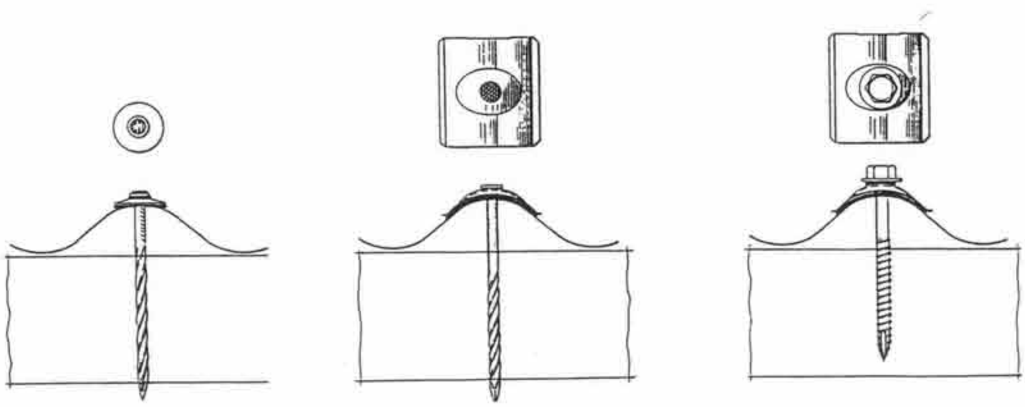
Since metal flashings are used in the peripheral area of the roof they must be fixed so that both edges are stiffened and both edges are fastened. Where possible two fasteners should be used on the profile and vertical fastening should be at 300mm centres.

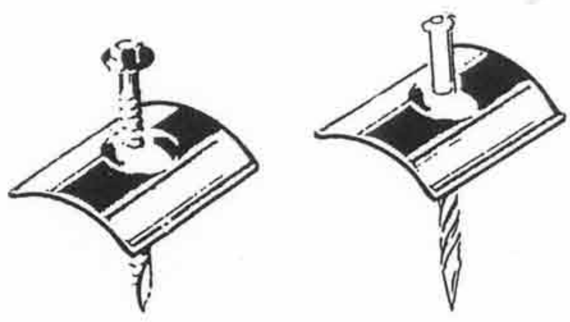
.55mm gauge must be used for the flashings and the flat unstiffened width of all metal flashings must be limited to 300mm.



ROOFING WASHERS

The type, size and gauge of nail or screw washers is critical and plastic sealing or synthetic rubber washers must be manufactured from a material that will withstand the effects of weather over the expected life of the fasteners. Metal load-spreading washers must be accurately formed to fit the profile and must not permanently deform under design load.





FASTENING PATTERNS

The following fastening patterns are calculated in kPa, which means that the values are valid only for purlin spacings of 1 metre.

To obtain the fastening pattern for different purlin spacings all of these values must be divided by the purlin spacing.

The different values are for .45mm and .55mm metal cladding and for fasteners with and without a load spreading washer.

Hit one, miss one, 7 Fasteners per metre.
.40mm = 2.8kPa .55mm = 3.5kPa
With L/S Washers .40mm = 4.9kPa .55mm = 6.3kPa

5 Rib Trapezoidal

Every rib, 6 Fasteners per metre.
.40mm = 2.4kPa .55mm = 3.0kPa
With L/S Washers .40mm = 4.2kPa .55mm = 5.4kPa

ROOF CLADDING

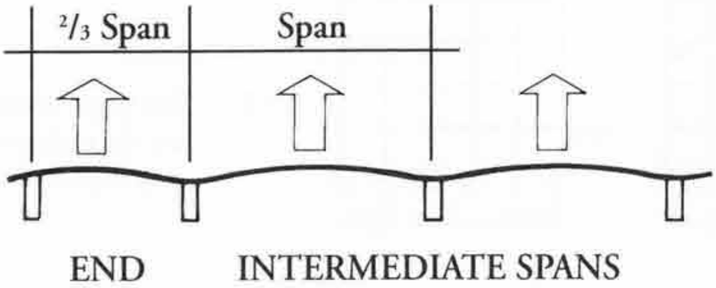
Failure of roof sheeting to resist cyclone wind loads can occur either by the roof cladding "pulling over" the head of the fasteners, or "pull-out" - the withdrawal of the fasteners from the purlins. The failure of one fastener in a critical location, such as at the gable end, can cause adjacent fasteners to be overloaded which can lead to a progressive failure of the roof structure.

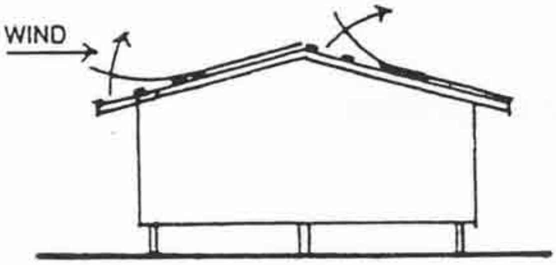
Any distortion in the shape of the roof profile at fastener locations can also have an adverse effect on the roof sheeting capacity to resist cyclone loads. The high load imposed by the fastener on the sheeting can cause the roof profile to dish around the head which leads to roof cladding "pull over".

For this reason load spreading washers must be used around the edges of all roofs in cyclone areas. All end spans must be reduced to 2/3rds of the Intermediate span.

Although closer spacing of fasteners can satisfy the "pullover" or "pull out" loads the fasteners may still be too far apart to prevent the roof profile from bending. This can cause the remaining fasteners to tear slots in the sheet cladding, which can then cause "pull over" sheet failure of the roof cladding. For this reason corrugated sheeting must be fastened at every second corrugation in roof areas subjected to high wind loads and not more than every third corrugation in low wind load areas. Trapezoidal cladding must be fixed on every rib.

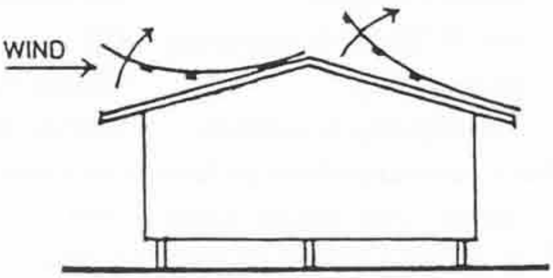
Under wind uplift loading when all spans of the roof sheet are assumed to deflect upwards, the crest of the profile and the fasteners are placed under tension and the pan under compression.





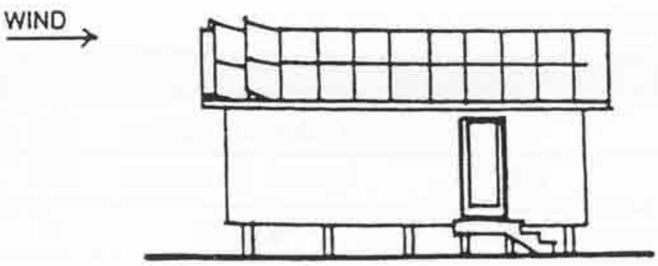
PROBLEM: **Wind lifts roof cladding**

SOLUTION: **Provide more fasteners**



PROBLEM: **Wind lifts roof cladding and purlins together**

SOLUTION: **Provide wire or strap fixing of purlins to rafters**



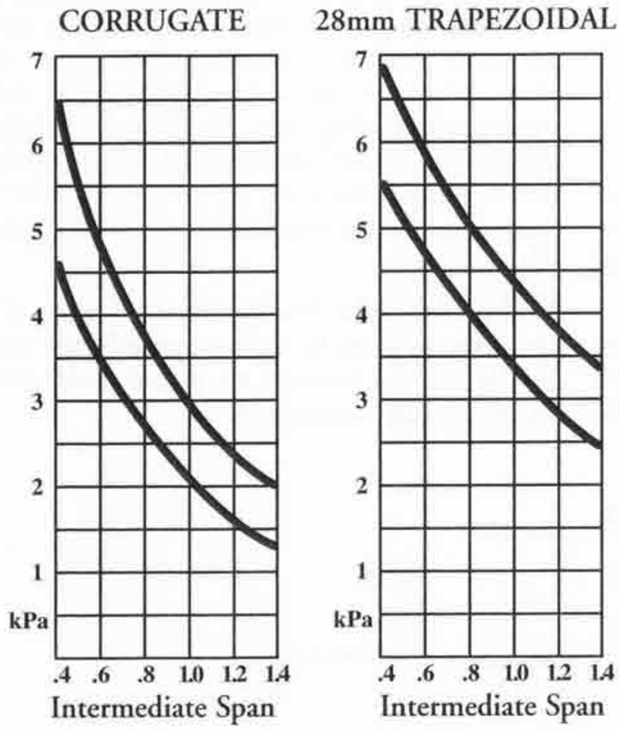
PROBLEM: **Wind peels roof cladding off purlins**

SOLUTION: **Provide additional fasteners through roof cladding.**
Barge flashing fixed on both edges.
Do not use a rolled edge flashing.

ROOF CLADDING DESIGN LOADS

Once the wind design load has been determined for the building site, the roof or wall cladding profile and the purlin spacing can be determined from the load span graph below.

Lower line is .45mm and Upper line is .55mm.



N.B. The spans shown are Intermediate spans and the end span must always be reduced to 2/3rds of the Intermediate spans.

SITE 1 (S1)

The roof cladding capacity determines the purlin spacing.

.45mm Corrugate	not suitable
Use .55 28mm rib trapezoidal	OK
Purlin spacing	900mm centres
Purlin spacings at periphery	500mm, 600mm and 900mm centres

An approximate value for pullover per fastener for screws or nails

.45mm - .4kN and for .55mm = .5kN

If profiled load spreading washers are used these values increase to:

45mm = .7kN and for .55mm = .9kN

Determine number of fasteners/ withdrawal loads

Using .55mm 5 rib trapezoidal cladding fastened every rib this load equals

6 x .5 = 3.0kN per 1/m

6 x .9 = 5.4kN per 1/m with load spreading washers

PURLIN SPACING	LOAD 4.72kPA	PERIPHERAL LOAD 7.08kPa
.5m	N/A	3.54kN L/S washers OK
.6m	2.88kN OK	4.25kN L/S washers OK
.9m	4.32 kN L/S washers OK	6.37kN *

* Suggest reducing purlin spacing to .75m or using additional pan fixed fasteners in this area.

Recommendations

Using a kl factor of 1.5 the edge distance on a 10m span = 2m periphery

Therefore the recommended fastening pattern is:

Fasten every rib with a 12# self drilling type screw or spiral shank nails

Fasten the periphery with a 12# self drilling type screw using load-spreading washers

Fasten the first 3 sheets from the barge of the roof with a 12# self drilling type screw and load-spreading washers.

Fasten the first three purlins using a 12# self drilling type screw and load-spreading washers and additional pan fixings.

SITE 2 (S2)

Determine profile and purlin spacing from load span graph. Lower line is .45mm and Upper line is .55mm.

The roof cladding capacity determines the purlin spacing.

.45mm Corrugate	OK
Purlin spacing	900mm centres
Purlins spacings at periphery	600mm, 660mm and 900mm centres

Determine number of fastners/ withdrawal loads

Using .45mm corrugate cladding fastened every second rib this load equals

7 x .4 = 2.8kN per 1/m

7 x .7 = 4.9kN per 1/m with load spreading washer

PURLIN SPACING	LOAD 1.66kPA		PERIPHERAL LOAD 2.49kPa	
.6m	.99kN	OK	1.49kN	OK
.66m	N/A		1.64kN	OK
.9m	1.49kN	OK	2.24kN	OK

Recommendations

Using a kl factor of 1.5 the edge distance on a 10m span = 2m

Therefore the recommended fastening pattern is:

Fasten every second corrugation with a 12# self drilling type screw or spiral shank nail

Fasten the first 3 sheets from the barge of the roof with a 12# self drilling type screw and load spreading washers.

Fasten the first three purlins using a 12# self drilling type screw.

NB: The load does not require load spreading washers but they are recommended at the periphery.

NOTES

DO'S AND DONT'S FOR CYCLONES

DO'S

- Keep yard clear of any potential flying debris.
- Trim down branches of trees that may break during a cyclone and become flying debris.
- Keep clear of all glazed openings during a cyclone.
- Tape all windows from corner to corner
- Stock up food supplies for use during and after a cyclone.
- Open leeward windows
- Vent soffits and gable ends to avoid full internal pressurization
- Keep a battery-operated radio to listen to broadcasts regarding the cyclone.
- If the house is in a flood prone area, move to higher ground before flooding occurs,
- If the house is in an area known to cause mudslides, vacate house and move to firm ground.
- Take cover under a desk or brace yourself in a doorway
- Keep clear of glazed areas, cabinets, cupboards, shelving or any heavy movable objects.

DONT'S

- Flatten roofing sheets when hammering nails or driving screws.
- Reuse metal roof cladding when the profile has been damaged
- Change pitch at the verandah
- Leave gaps or allow slackness between joints and connections. Make all connections tight.
- Use jolt head nails on metal connectors.
- Use undersized members or connectors.
- Use nail plates on only one side of a truss.
- Punch holes in metal straps with a nail or other sharp object. Always drill holes or use pre-punched straps
- Use roofing iron for strapping
- Build a low-set house in an area known to be flood-prone.
- Rely solely on skew nailed joints or wire dogs.
- Nail metal straps in one line, but stagger the nails.
- Use untreated timber for external use.
- Stand near glazed openings during a cyclone.
- Wander out after the cyclone. The lull may be temporary.
- Go near broken down power lines.

AFTER A CYCLONE

Carefully inspect all structural connections and replace, tighten or strengthen any that have become loose or have failed. The next cyclone may destroy a building that has become weakened by previous cyclones.

Check that your building complies with the requirements and recommendations in this booklet.