MANUAL FOR
CYCLONE RESISTANT CONSTRUCTION

TABLE OF CONTENT

1 BASIC KNOWLEDGE OF CYCLONE

A tropical cyclone is a relatively small, intensely developed low-pressure cell that usually occur over warm oceans. Its diameter can range between 200 and 2,000 km. It is characterized by a warm centre, very steep pressure gradients and strong cyclonic (clockwise in the southern hemisphere) winds near the Earth's surface. Tropical cyclones with a maximum wind speed of less than 60 km/h are called tropical depressions; when the maximum wind speed ranges between 60 and 110 km/h, they are tropical storms, and when the maximum wind speed exceeds 110 km/h, they are called tropical cyclones. (In the North Atlantic and eastern North Pacific regions it is called "hurricanes", in the western North Pacific "typhoons".)

1.1 Formation

The process by which a disturbance in the pressure pattern forms and subsequently strengthens into a tropical cyclone depends on at least three conditions:

- Developing tropical cyclones gather heat and energy through contact with warm ocean waters. This usually happens between 5 and 20 North and South.
- The addition of moisture by evaporation of seawater from the sea surface powers them like giant heat engines, i.e. it draws its energy from the evaporation of seawater under the storm.
- A wind pattern near the ocean surface that spirals air inward, is also necessary.

The net result of these processes is a towering column of spiraling air with an intense low pressure in its centre. Bands of thunderstorms form, allowing the air to warm further and rise higher into the atmosphere.

1.2 Structure

The centre, or eye, of a tropical cyclone is relatively calm and warm. The eye itself is clear, mainly because of gently subsiding air within it. The eye is extremely warm near the top of the storm circulation, reaching temperatures as much as 10C greater than that of the undisturbed environment at the same altitude. Near the sea surface the air has virtually the same temperature through the storm.

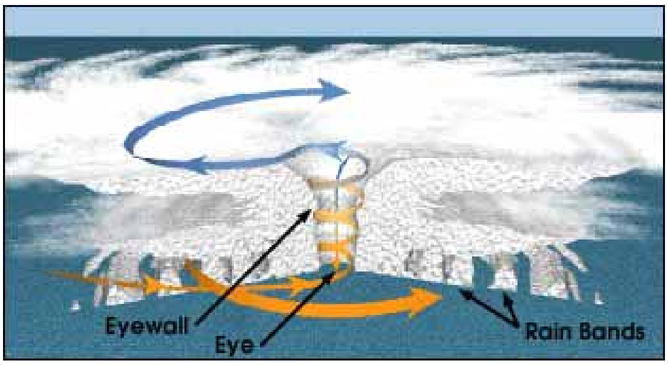


Figure 1: Cyclone structure

A spectacular wall of cloud (mainly cumulonimbus) rings the edge of the eye from sea level to heights of over 15 km. This ring of cloud, called the eye wall, maybe tens of kilometers thick, while a dense cirrus and altostratus overcast may extend outward several hundred kilometers from the eye wall. The most violent activity takes place in the eye wall. At the top of the eye wall, most of the air is propelled outward, increasing the air's upward motion.

1.3 Lifetime

Once a mature tropical cyclone forms, it can last while the atmospheric and oceanic conditions remain favorable – duration of 1 week is typical. Tropical cyclones decay when they move over land (called landfall) or cold ocean water - more rapidly over land, particularly if the terrain is rough.

1.4 Tracks

Tropical cyclones move forward at different speeds. On average a cyclone may travel 200 km in a day. Although tropical cyclones occur in definite regions of the world and generally moves in a westerly direction, their precise tracks are erratic and very difficult to predict.

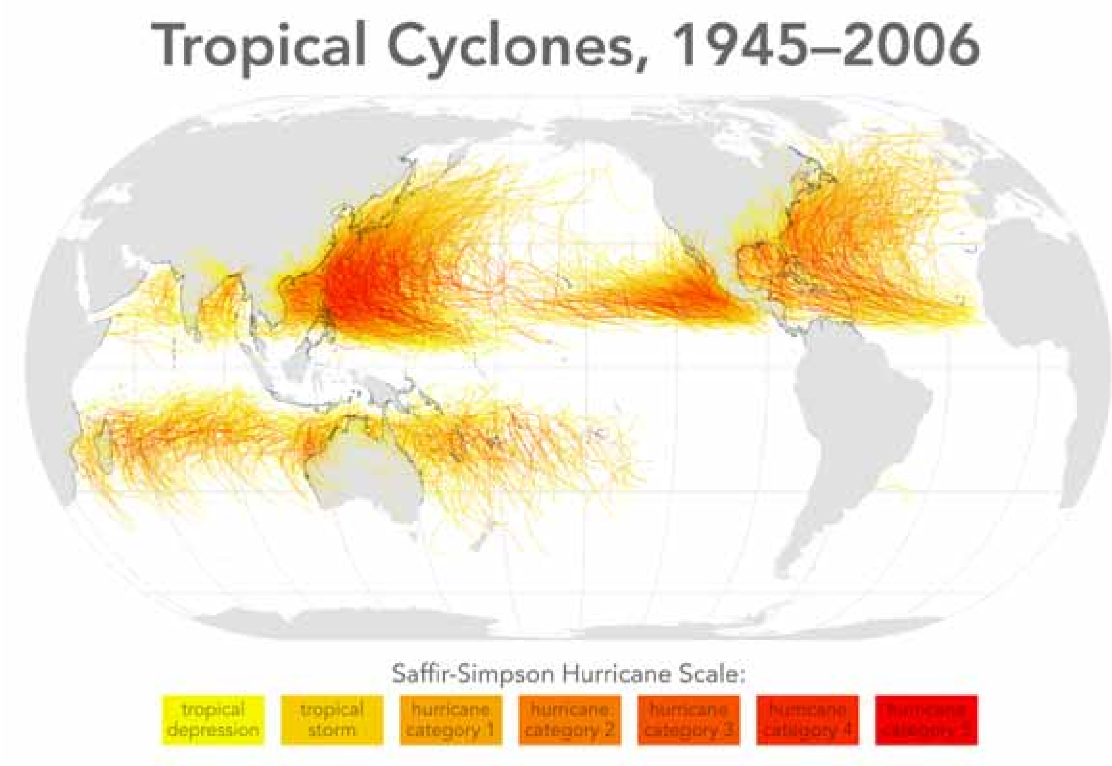


Figure 2: Tropical cyclone tracks 1945-2006

1.5 The weather associated with tropical cyclones

Tropical cyclones are always accompanied by torrential rain. A single storm may yield up to 3,000 mm of rain. Heavy rains sometimes occur many days after landfall and are also very destructive. It may give rise to floods.

Because of the steep pressure gradient, strong winds occur. The wind speed rises rapidly from nearly zero in the eye to its maximum value at a radius between 10 and 100 km from the centre. The strongest winds occur near the leading edge ("in front") of the storm.

The destruction associated with tropical cyclones results not only from the force of the wind, but also from the storm surge and the waves it generates. The storm surge is experienced as a rapid rise of sea level near that portion of the eye wall associated with onshore winds, sometimes reaching a height of more than 6 meters and accompanied by very large wind-driven waves. Much of the death toll in tropical cyclones is due to the storm surge. The net result of the raised sea level, strong winds and torrential rains is to inflict severe damage on coastlines affected by the storm, especially those that are low-lying.

2 EFFECTS OF CYCLONES ON HOUSING

Contrary to popular belief, few houses are blown over. Instead, they are pulled apart by winds moving swiftly around and over the building. This lowers the pressure on the outside and creates suction on the walls and roof, effectively causing the equivalent of an explosion.

Whether or not a building will be able to resist the effects of wind is dependent not so much upon the materials that are used but the manner in which they are used. It is a common belief that heavier buildings, such as those made of concrete block, are safer. While it is true that a well-built and properly engineered masonry house offers a better margin of safety than other types of buildings, safe housing can be and has been provided by a variety of other materials including wood and many others.

2.1 Catastrophic Failures

2.1.1 Foundations

The uplift forces from cyclone winds can sometimes pull buildings completely out of the ground. In contrast to designing for gravity loads, the lighter the building the larger (or heavier) the foundation needs to be in cyclone resistant design. Ignoring this precept has led to some dramatic failure of long span, steel-framed warehouses.

2.1.2 Steel Frames

A common misconception is that the loss of cladding relieves the loads from building frameworks. There are several circumstances where the opposite is the case and where the wind loads on the structural frame increases substantially with the loss of cladding.

Usually the weakness in steel frames is in the connections. Thus economizing on minor items (bolts) has led to the overall failure of the major items (columns, beams and rafters).

2.1.3 Masonry Houses

These are usually regarded as being safe in cyclones. There are countless examples where the loss of roofs has triggered the total destruction of un-reinforced masonry walls.

2.1.4 Timber Houses

The key to safe construction of timber houses is the connection details. The inherent vulnerability of lightweight timber houses coupled with poor connections is a dangerous combination, which has often led to disaster.

2.1.5 Reinforced Concrete Frames

The design of reinforced concrete frames needs to be exercised to ensure that the concrete frames can accommodate the wind forces. There have been a few isolated examples where, ignoring this, has led to disaster.

2.2 Component Failures

2.2.1 Roof Sheeting

This is perhaps the commonest area of failure in cyclones. The causes are usually inadequate fastening devices, inadequate sheet thickness and insufficient frequencies of fasteners in the known areas of greater wind suction.

2.2.2 Roof Tiles

These were thought to have low vulnerability in storms but past cyclones have exposed the problem of unsatisfactory installation practices.

2.2.3 Rafters

Of particular interest in recent cyclones was the longitudinal splitting of rafters with the top halves disappearing and leaving the bottom halves in place. The splitting would propagate from holes drilled horizontally through the rafters to receive holding-down straps.

2.2.4 Windows and Doors

After roof sheeting, these are the components most frequently damaged in cyclones. Of course, glass would always be vulnerable to flying objects. The other area of vulnerability for windows and doors is the hardware latches, bolts and hinges.

2.2.5 Walls

It is not uncommon for un-reinforced masonry to fail in severe cyclones. Cantilevered parapets are most at risk. But so are walls braced by ring beams and columns have remained safe.

2.3 Damaging Effects of Cyclone on Houses

Due to the high wind pressure and improper connection of the house to the footings it can be blown away

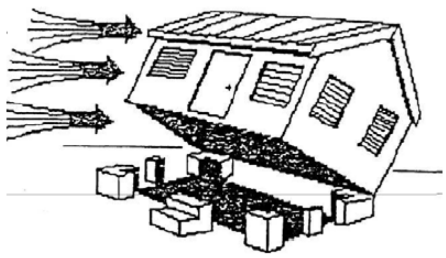


Figure 3: Blown away houses

Roofing materials not anchored can be blown away

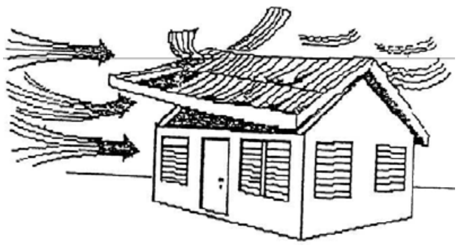


Figure 4: Roof damaged

Lightweight veranda roofs are more susceptible to damage due to high wind speed

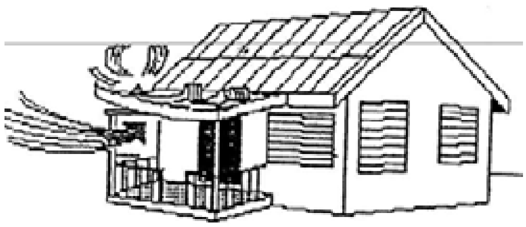


Figure 5: Veranda damaged

When cyclones are accompanied with heavy rain for a long duration, the buildings can be damaged due to flooding also. Building contents are spoiled due to rain when roofing sheets fly away.

Figure 6: Cyclone and flood

3 TEN KEY POINTS OF CYCLONE RESISTANT CONSTRUCTION

Ten key points of cyclone resistant construction are the results of more than 20 years working experiences in the construction and reinforcement of housing in the cyclone prone areas of Vietnam. These key points are also based on the design standard on wind load and local knowledge of housing construction.

The ten key points can be applied to almost any type of building, regardless of the type of structure or the type of materials that have been used. Each point describes a principle that when applied will reduce the risk of damage to the building or loss of materials. This chapter presents how to apply the ten key points to components of buildings and materials. These ten key points are not only applicable to strengthen existing buildings, but also to build new houses.

3.1 Choose the location to minimize the wind force

Figure 7: Key point No.1

The location of the building is important. We often have little choice in the matter, perhaps because of financial constraints. It is, therefore, to recognize when a building is being located in a more vulnerable area. The rational response would be to build a stronger-than-normal house. It is also important to take the advantages of the existing topography such as mountains, buildings, trees, etc to avoid the direct impacts of the wind force. Although cyclonic storms always approach from the direction of the sea towards the coast, the wind velocity and direction relative to a building remain random due to the rotating motion of the high velocity winds. In non-cyclonic region where the predominant strong wind direction is well established, the area behind a mound or a hillock should be preferred to provide for natural shielding. Similarly a row of trees planted upwind will act as a shield. There are four main types of topography and each type requires specific techniques to reduce the cyclone impacts.

Figure 8: Shielding of house by hillock

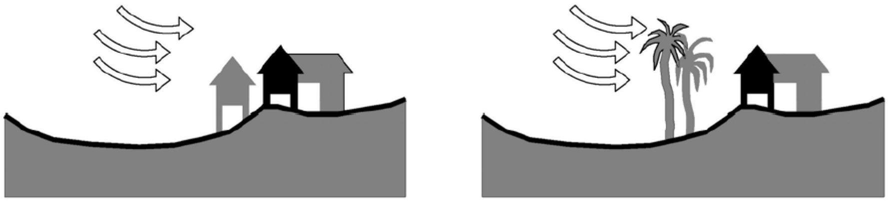
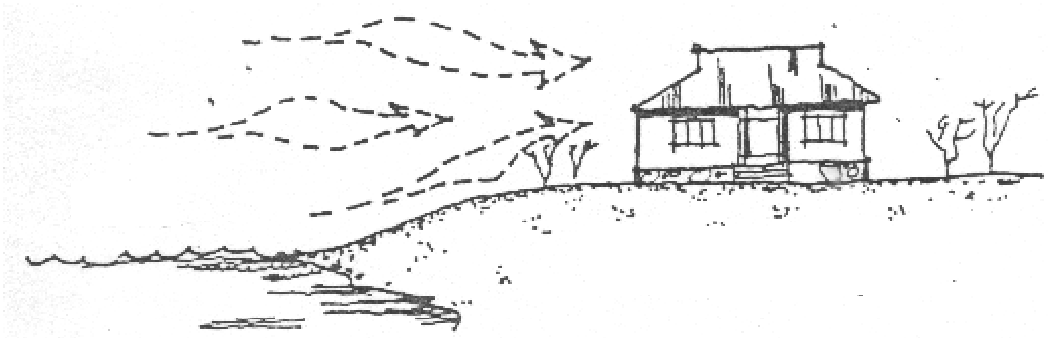


Figure 9: Take advantages of natural barriers

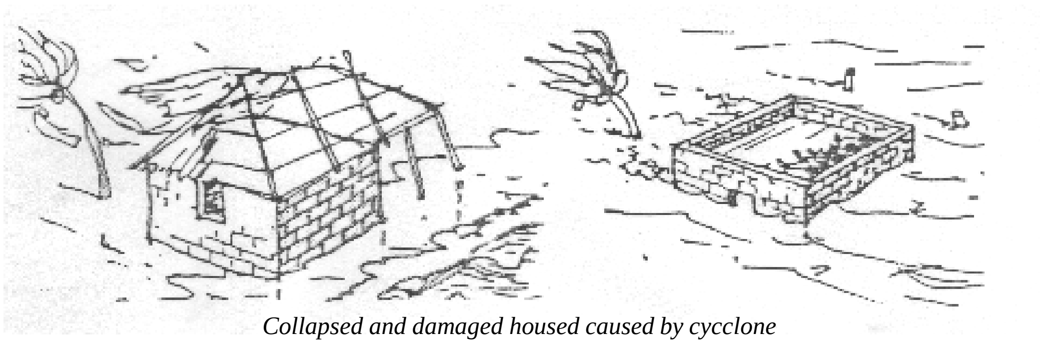
3.1.1 Topography type 1

Topography type one is the areas along coastal lines, along rivers, open areas, or top of the hills where have almost no objects, or trees to shield the wind (Figure 10). It is extremely vulnerable to build the house in the topography type one, as all components of the house will be exposed to the direct impacts of the cyclone in all directions. Therefore, in this area the house should be built stronger than the normal house.



Topography type 1

Figure 10: Topography type 1



Collapsed and damaged housed caused by cycclone in tophography type one

Figure 11: Collapsed houses caused by cyclones

In hilly areas, construction along ridges should be avoided since they experience an accentuation of wind velocity whereas valley experiences lower speeds in general. Though some times in long narrow valleys wind may gain high speed along valley.

In cyclonic regions close to the coast, a site above the likely inundation level should be chosen. In case of non-availability of high-level natural ground, construction should be done on stilts with no masonry or cross bracings up to maximum surge level, or on raised earthen mounds to avoid flooding/inundation but knee bracing may be used (Figure 12).

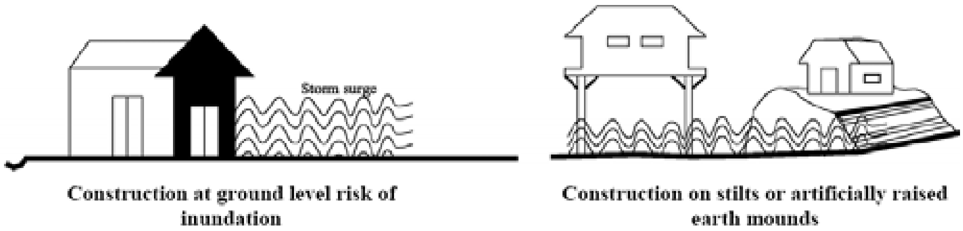
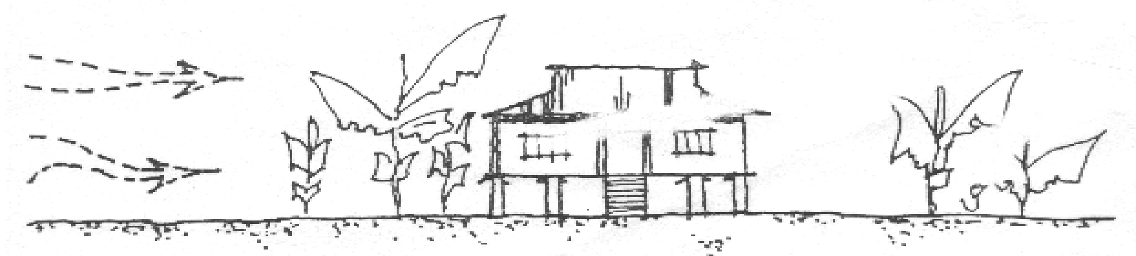


Figure 12: Choose foundation levels

3.1.2 Topography type 2

Topography type two is the flat land with few trees, which can be used as a windbreak to reduce the impacts of cyclones on housing. The principles applied for topography type one would also be applied in this topography.



Topography type 2

Figure 13: Topography type 2

3.1.3 Topography type 3

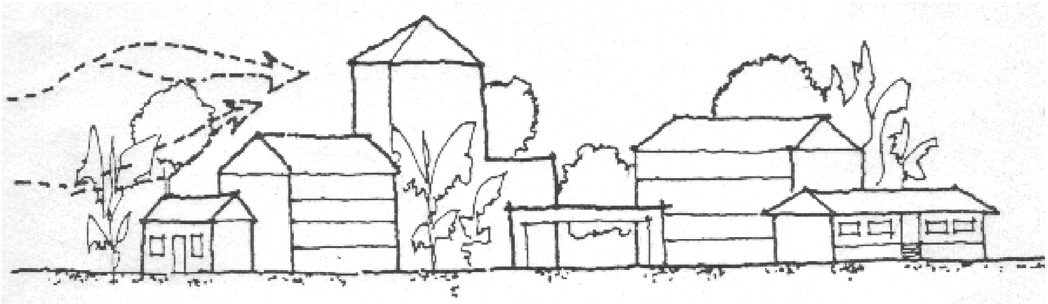
The topography type three is the area having many buildings, and trees. For example, the sub-urban areas or the areas along the thick forests can be classified into this topography.

Many buildings and trees may create some unfavorable bag that attract the wind and cause the local suction force on the roofs. The weak houses located near strong buildings or easy broken trees will be very vulnerable. Therefore, it is important to reinforce the weak parts of the house, for example, the roof's covers, gables and roof's structures. Trees need to be trimmed to avoid their impacts on the houses if they broken.

3.1.4 Topography type 4

Topography type four is the area having high density of buildings and trees. This topography is relatively good to in terms of cyclone resistance. However, there are some weak points need to be considered:

- Many buildings with different heights cause some areas, and spaces very vulnerable to cyclones
- Different rigidities of the buildings increase the negative impacts of the weaker houses
- Tree planting follows the landscape architecture rather than the cyclone risk reduction principles
- It is difficult to choose the location for housing due to financial and other constraints. The viable option is to reinforce and retrofit the house.

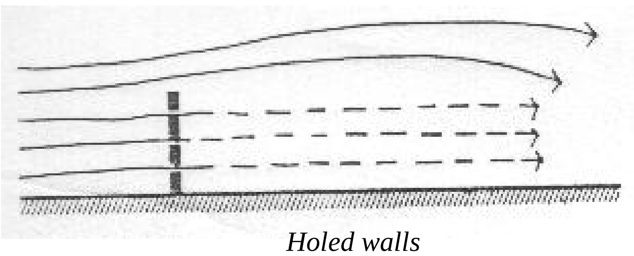


Topography type 4

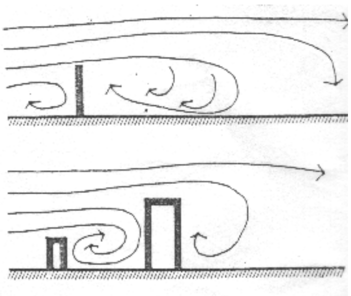
Figure 14: Topography type 4

Things need to be considered when choosing the location to build a new house:

- Take advantages of natural barriers such as trees, small hills, and hedgerow that can reduce the wind force, particularly the find force from the main wind direction
- Be careful with the location in the high hill, or near the peak of the hill as the wind speed can increase up to 50%.
- Be careful in the valley areas as the wind speed, and wind force are very unpredictable and can be increased rapidly.
- The neighboring houses can change the wind force and wind direction. Some neighboring houses can increase the suction force on the gables and toproofs. Therefore, it is important to reinforce the weak components that located within the impact zones of the neighboring houses.
- Avoid the solid and high wall because it may create the whirlwind and this will be dangerous to housing. If the wall is designed to reduce the wind force it needs to have holes that allow winds pass through so that the whirlwind will not form in the leeward.
- It is important to determine the main wind direction in order to reinforce the components that are vulnerable to that wind direction.

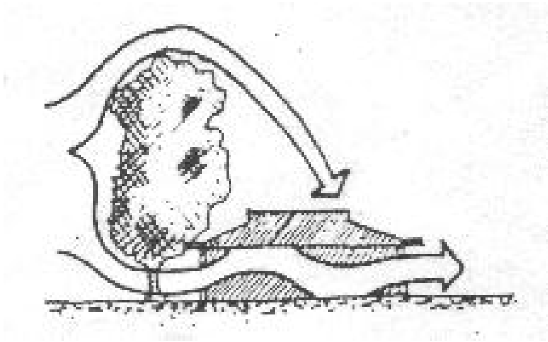


Holed walls

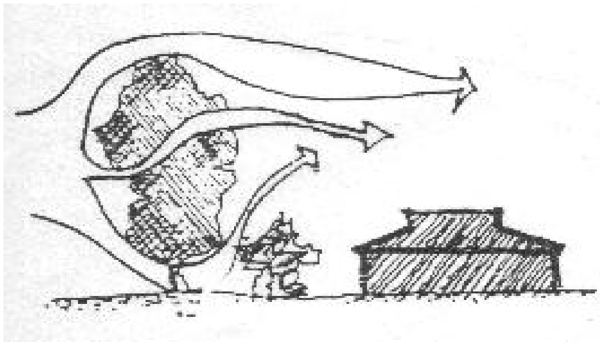


Solid walls

Figure 15: Walls



Thick tree row



Ventilated tree row

Figure 16

3.2 Build a house with a simple shape to reduce negative pressure

Figure 17

We do have control over the shape of new buildings and shape is the most important single factor in determining the performance of buildings in cyclones. Simple, compact, symmetrical shapes are best. The square plan is better than the rectangle since it allows high winds to go around them. The rectangle is better than the U or L-shaped plan. This is not to say that all buildings must be square. But it is to say that one must be aware of the implications of design decisions and take appropriate action to counter negative features. The best shape to resist high winds is a square.

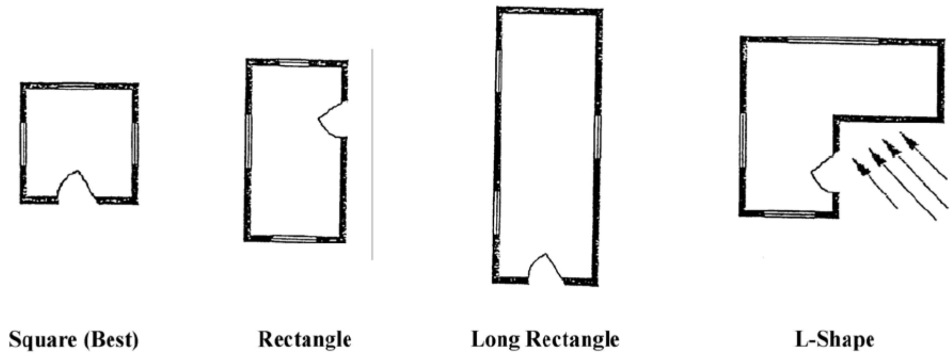


Figure 18

- L shape and U shape are not good as they create unfavorable bags that attract the wind
- Spacious rooms, few partition walls, or too high walls are weak and easy to collapse

- If other shapes are desired, efforts should be made to strengthen the corners
- If longer shapes are used, they must be designed to withstand the forces of the wind.
- Most houses are rectangular and the best layout is when the length is not more than 2.5 times the width.

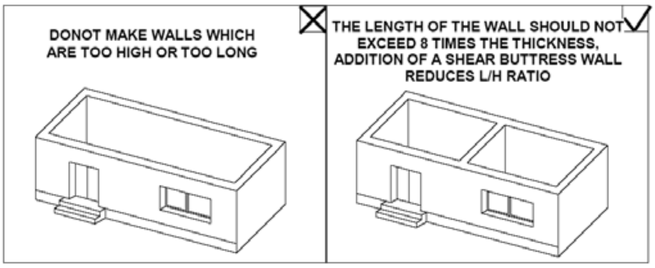
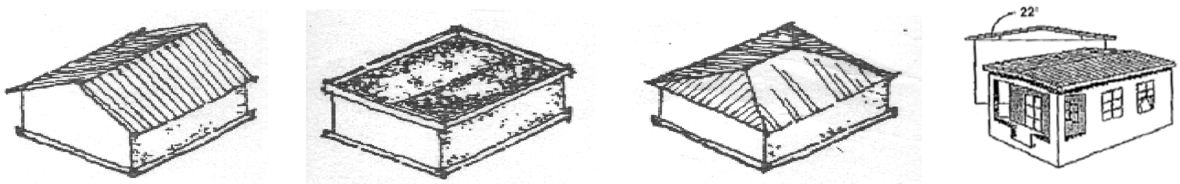


Figure 19

3.2.1 Roof shape

The roof shape is very important. The flat reinforced concrete roof is the best to avoid the cyclone impacts. Hip roofs are best, they have been found to be more cyclone resistant than gable roofs.



High gable roof *RC flat roof* *Hip roof* *Lightweight flat roof*

Figure 20

Roof shape	Strengths	Weaknesses
High gable roof	Easy to construct Easy to extend the house in the both sides	Weak gables Large areas exposed to the cyclone
RC flat roof	Cyclone resistant roofs Can be used for the safe shelter in flooding	Costly, Difficult to build
Hip roof	Reduce the areas of the gables Reduce impacts of the wind High rigidity of the roof	Costly Difficult to build
Lightweight flat roof	Reduce the height of housing	Easily blown off in high winds

In terms of cyclone risk reduction, it needs to avoid unnecessary and complicated roof shapes. However, it is important to respect the local culture and local weather conditions. Therefore, if necessary it is important to assess the weak parts of the house in order to reinforce and make them safer.

3.3 Build the roof at an angle of 30^0 to 45^0 to prevent it from lifting off

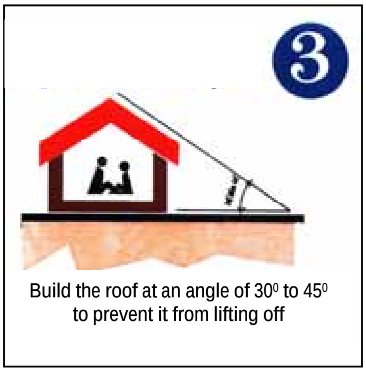


Figure 21

In order to lessen the effect of the uplifting forces on the roof, the roof pitch should be from 30º to 45^0.

General considerations:

- The roofs with proper slope can reduce the uplifting force
- Avoid a low-pitched roof and try to use a hip roof or a high-pitched gable roof

Suction force on the roof depends on the angle of the roof. For example, with the same topography condition, the same house type but different heights and roof angles, the roofs will have different negative wind pressures (see Tab.)

Table 1: Negative wind pressure in different roof angles

Topography type	House's height	Wind pressure (kg/m^2)	Wind speed (km/h)	Negative wind pressure on roof	
				Angle < 20^0	Angle >20^0
1	5	162	51	275	243
1	10	186	54,5	316	279

The negative wind pressure on the roof reduces its value when the roof angle reaches to 45^0. Traditional houses often have the roof angle of 33^0 – 36^0 for the main roof and 10^0 – 13^0 for the veranda. Therefore, the veranda needs to be reinforced the connection between the roof cover and the veranda structure.

Almost all roof cover materials such as iron sheets, fibrocement tile need an angle of 30^0 to 45^0. However, in some large span building such as factory, and stores the smaller roof angles have been applied to reduce the height. If the roof angle is smaller than 22^0, there roof needs to be reinforced to avoid lifting off.

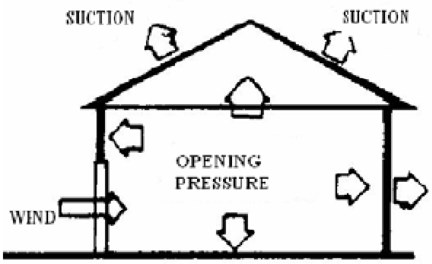
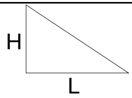


Figure 22

To help the builders determine the angle of the roof, the table below shows how to do it.

Table 1: Roof angle measurement

Roof angle (degree)	Slope (%)	 H, L	
		L (cm)	H (cm)
30	58	100	58
32	63	100	63
34	68	100	68
36	72	100	72
38	78	100	78
40	84	100	84
42	90	100	90
44	97	100	97
45	100	100	100

3.4 Avoid wide roof overhangs, separate the veranda structure from the house

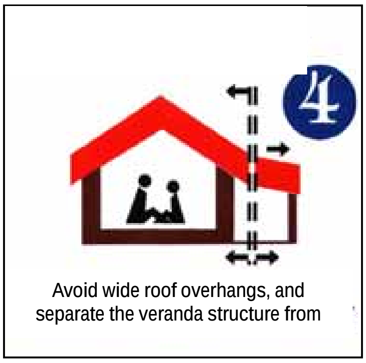
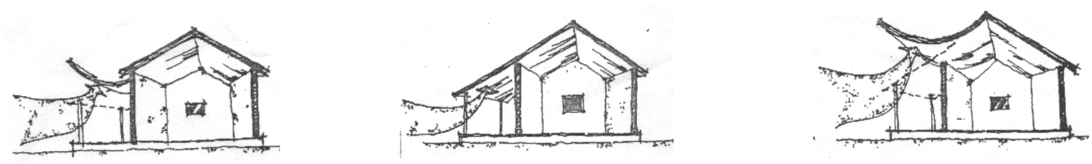


Figure 23

Avoid overhanging roofs as high wind force builds up under them. If overhangs or canopies are desired, they should be braced by ties held to the main structures.

If overhang needed, it should not be more than 450mm at verges or eaves.

Build veranda and patio roofs as separate structures rather than extensions of the main building. Use flexible joints for the veranda and main structure connections so that when there is a strong cyclone, the veranda may blow off without damaging the rest of the house.



Seperated veranda during cyclone *Non separated main roof and verada during cyclone*

Figure 24

Located in tropical monsoon, many houses need to have wide roof overhangs to reduce the impacts of rains and sunlight. These overhangs are very vulnerable to strong winds. Therefore, the roof overhangs need to be reinforced.

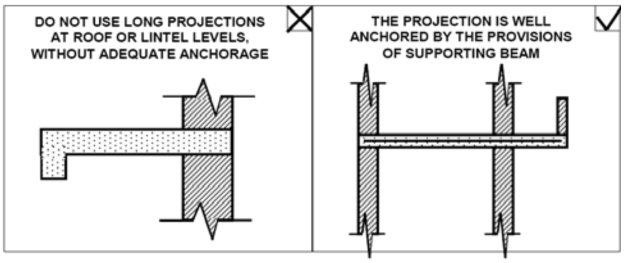


Figure 25

If necessary to have roof overhangs, try to avoid wide roof overhangs. Some parts of the house do not necessarily to have the roof overhangs such as the gables.

The veranda should be separated from the main structure because the veranda is the opening part of the house, which is subjected to both push and pull wind forces from below and above the roof. Therefore, it is often destroyed before the main structure.

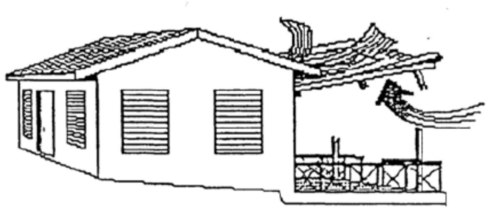
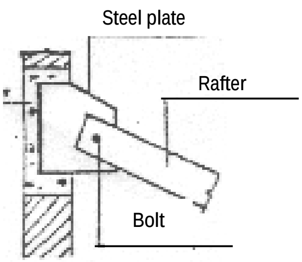
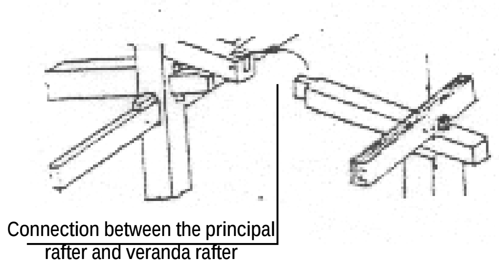


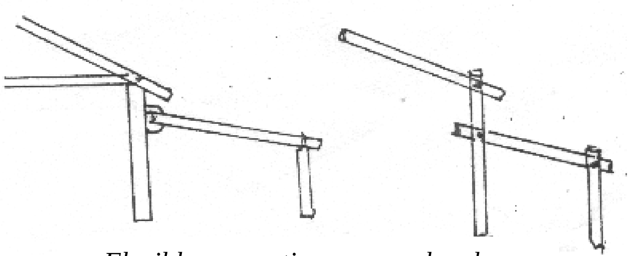
Figure 26

When there is a strong cyclone exceeding the resistant capacity of the house, the veranda is often the first part to be broken. If the veranda is not separated from the main roof, its failure will affect the main roofs. Therefore separation the veranda from the main roofs to avoid the damage caused the failure of the veranda. Below are some techniques to separate the veranda from the main roof structure. The most effective method is to use the flexible connection.





Flexible connections



Flexible connections among bamboo components

Figure 27

3.5 Make sure the foundations, walls, roof structure and roof covering are all firmly fixed together

Make sure the foundations, walls, roof structures, and roof coverings are all firmly fixed together

Figure 28

Make sure all components of the house are firmly fixed together:

- Between foundation and ground
- Between foundation and column
- Between foundation and wall
- Between column and wall
- Between rafter and column
- Between purlin and rafter
- Between common rafter and purlin
- Between lath and common rafter
- Between covering and lath or purlin

If one of those above-mentioned connections is weak, the all structure of the house will be affected.

3.5.1 Foundation and ground connection

The foundation is the part of the house, which transfers the weight of the building to the ground. It is essential to construct a suitable foundation for a house as the stability of a building depends primarily on its foundation. Buildings usually have shallow foundation on stiff sandy soil and deep foundations in liquefiable or expansive clayey soils. It is desirable that information about soil type be obtained and estimates of safe bearing capacity made from the available records of past constructions in the area or by proper soil investigation. In addition the following parameters need to be properly accounted in the design of foundation.

Effect of surge or flooding: Invariably a cyclonic storm is accompanied by torrential rain and tidal surge (in coastal areas) resulting into flooding of the low-lying areas. The tidal surge effect diminishes as it travels on shore, which can extend even up to 10 to 15 km. Flooding causes saturation of soil and thus significantly affects the safe bearing capacity of the soil. In flood prone areas, the safe bearing capacity should be taken as half of that for the dry ground. Also the likelihood of any scour due to receding tidal surge needs to be taken into account while deciding on the depth of foundation and the protection works around a raised ground used for locating cyclone shelters or other buildings.

Buildings on stilts: Where a building is constructed on stilts it is necessary that stilts are properly braced in both the principal directions. This will provide stability to the complete building under lateral loads. Knee bracings will be preferable to full diagonal bracing so as not to obstruct the passage of floating debris during storm surge.

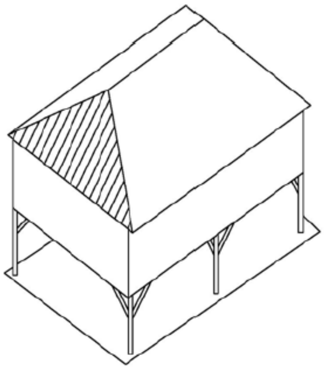


Figure 29: Building on stilts

a. *Slab or Raft Foundation*

- Used on soft soils.
- Spread the weight over a wider area

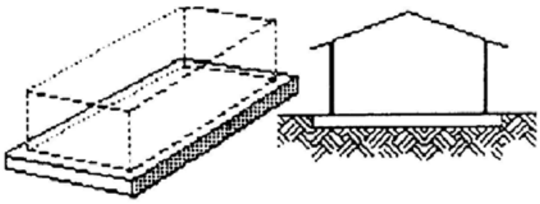


Figure 30

b. *Strip Foundation*

- Used for areas where the soil varies.
- Most common.
- Supports a wall.

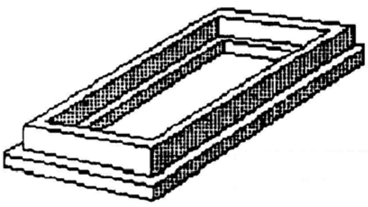


Figure 31

c. *Pile Foundation*

- Deep foundations for small or large buildings
- Under reamed piles often used in expansive clay or alluvial soils

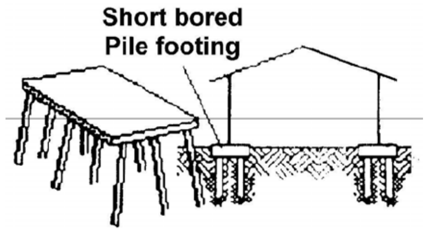


Figure 32

d. *Pad Foundation*

- Used on firm soil.
- Used for columns & poles

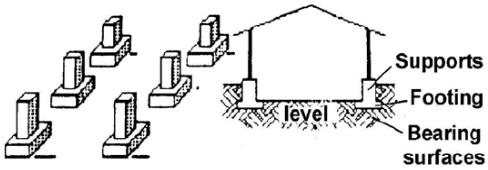
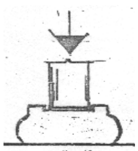
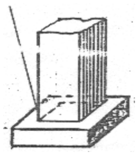


Figure 33

3.5.2 Foundation and column connection



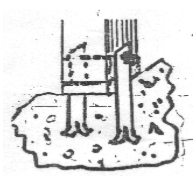
Foundation of traditional house can bear the cross force



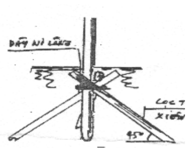
Weak connection between column and foundation in transition house

Bamboo/timber column fixed in the ground

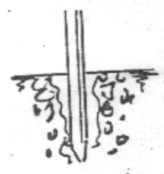
Figure 34



Reinforced connection between wooden column and RC foundation



Reinforced connection between bamboo column and earth foundation

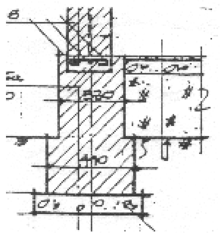


Reinforced connection between column and earth foundation by making fast with clay and stones

Figure 35

3.5.3 Foundation and wall connection

The foundation made by brick or stone needs an edge-beam that extends from column to column to prevent the base of the house from spreading. In order to strengthen the connection between foundation and wall, the base course (the first five brick layers from the edge-beam) of the wall should be used high-grade mortar (#75) to build.



Foundation-wall connection

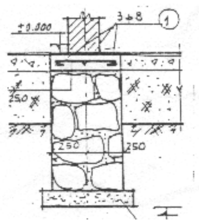
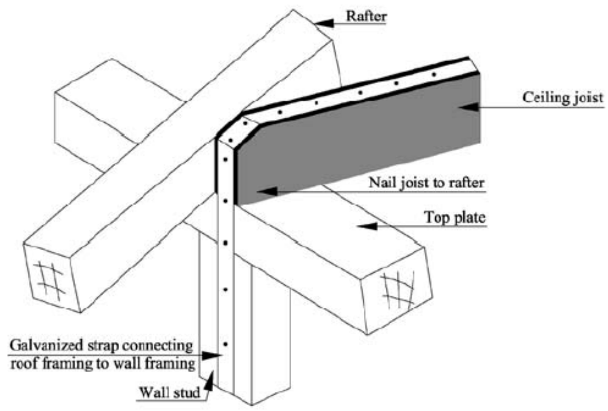


Figure 36

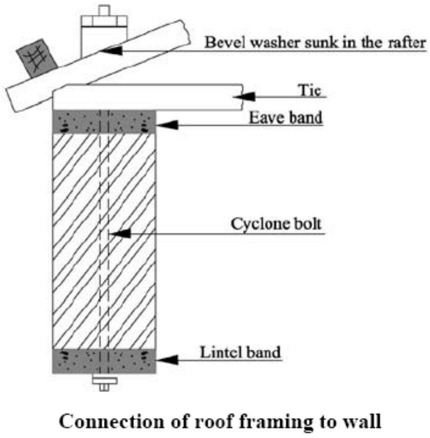
3.5.4 Column and rafter connection

The connection of roof framing to the vertical load resisting elements i.e. wall or post, by providing properly designed anchor bolts and base plates is equally important for overall stability of the roof. The anchoring of roof framing to masonry wall should be accomplished through anchor belts embedded in concrete cores. The weight of participating masonry at an angle of half horizontal to 1 vertical should be more that the total uplift at the support. In case of large forces, the anchoring bars can be taken down to the foundation level with a structural layout that could ensure the participation of filler and cross walls in resisting the uplift.

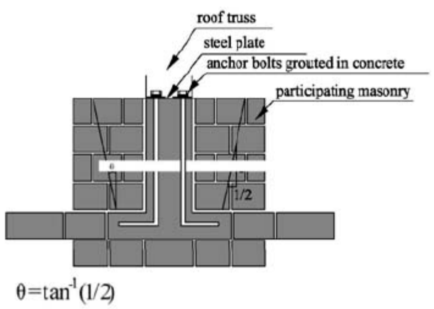


Connection of roof framing to wall traming

Figure 37



Connection of roof framing to wall

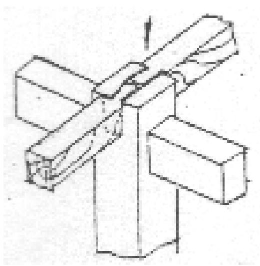


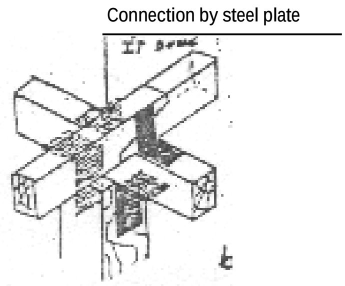
Anchoring of roof framing in masonry

Figure 38

a. Wooden column and wooden rafter

- Use the traditional dapped joints or use steel straps for the connection between wooden column and wooden rafter. Do not use only nails for this connection.



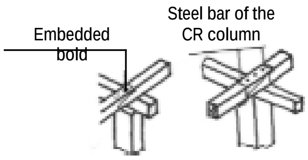


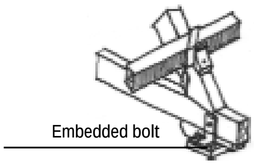
Column and rafter connection

Figure 39

b. Reinforced concrete column and wooden rafter connection

- Use the embedded bolt in the RC column or use the still bar of the RC column to connect the wooden rafter.





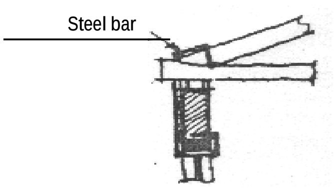
RC column and rafter

Figure 40

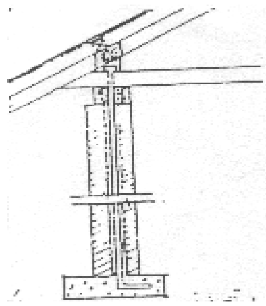
c. Brick column and wooden rafter

Due to the low bearing power of the brick column, the embedded bolt in the brick column cannot sustain the strong wind force. Therefore, it requires other techniques for this connection.

Use still bar to fix the rafter into the lintel or the ring beam or even connect the rafter to the foundation through steel bar (Figure 41)



Rafter and brick column connection

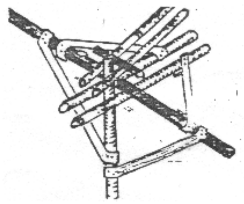


Rafter and brick column connection

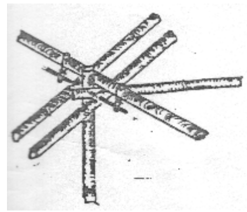
Figure 41

d. Bamboo column and bamboo rafter connection

Hinge joint is very good to fix bamboo components together. This joint can resist the wind force.



Reinforcement of rafter and columm

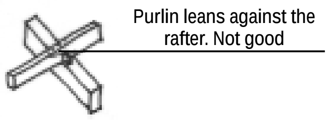


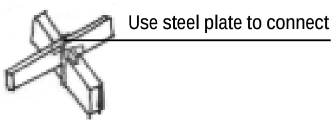
Connection among purlin, rafter and column

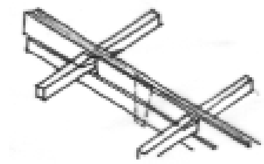
Figure 42

3.5.5 Rafter and purlin connection

Rafter and purlin connection is very important, however the purlin is often connected to the rafter by nail. Therefore, the roof is often lifted off by a strong wind. Below are some suggested connections.







Rafter and Purlin connection

Figure 43

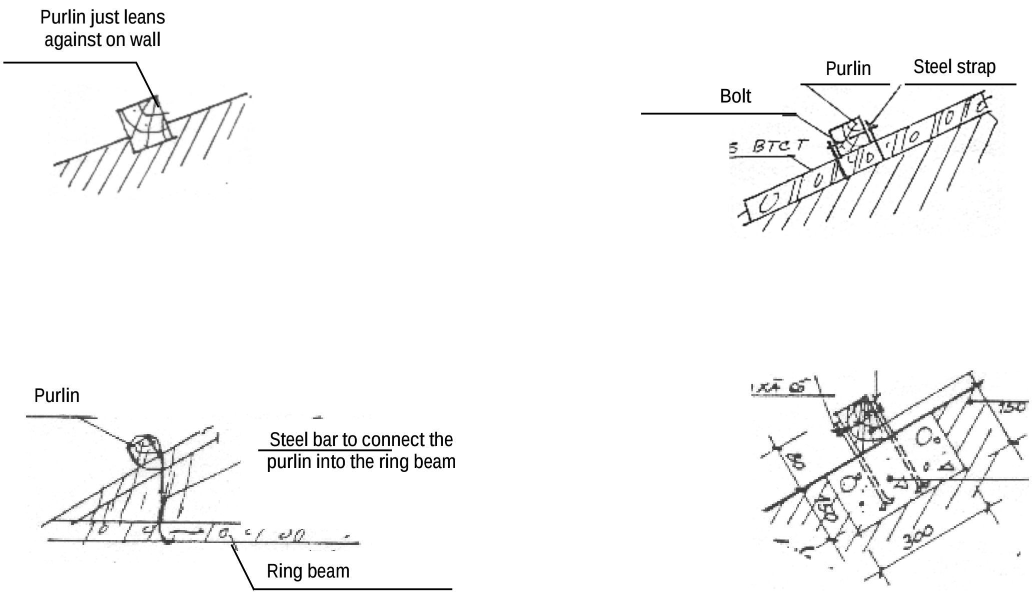
To connect the bamboo components, the plastic wire and hinge are traditionally used which is good in terms of typhoon resistance.

3.5.6 Gable end and purlin connection

Do not lean the purlin against on the gable ends, as this connection is not strong enough to sustain the wind force.

The purlin and gable end connected by an embedded steel strap in the gable is better, however the bearing capacity of the gable wall is not high. Therefore, the gable wall is often damaged when there is a strong cyclone.

A better solution is to use a reinforced concrete beam on the top of the gable wall, fix the steel strap into this beam and connect the purlin into the steel straps. Another technique is to connect the purlin into the ring beam (Figure 44).

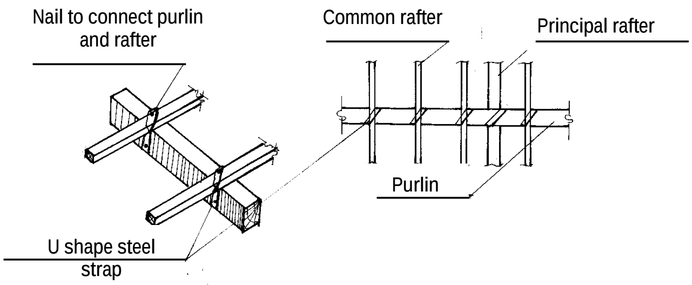


Purlin and gable wall connections

Figure 44

3.5.7 Purlin and common rafter connection

Common rafter is often connected to purlin by nail. Therefore, the roof is often lifted off due to the failure of these connections. It is important to use U shape steel strap for these connections



Common rafter and purlin connection

Figure 45

3.5.8 Lath and common rafter connection

The lath is attached to common rafter by nail.

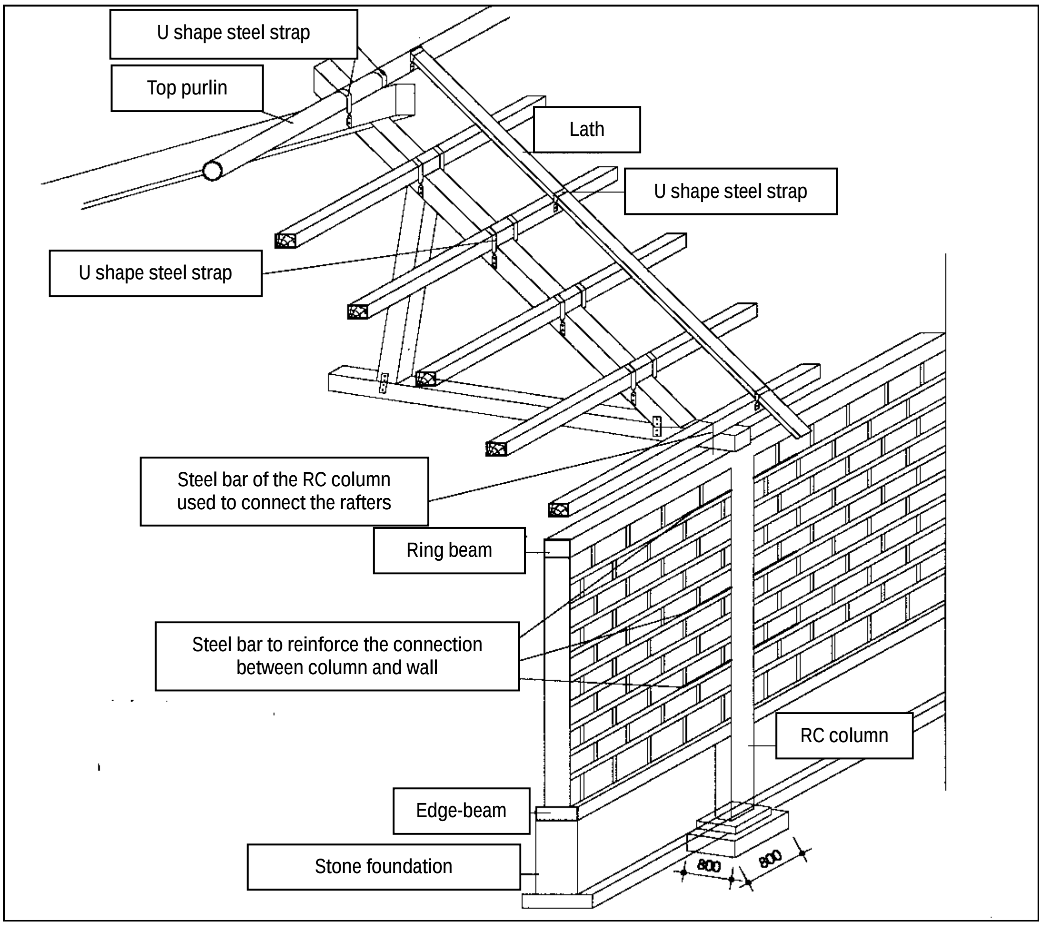


Figure 46

3.5.9 Securing the Ridge

If the rafters are not secure, the ridge can fall apart when strong wind passes over the roof.

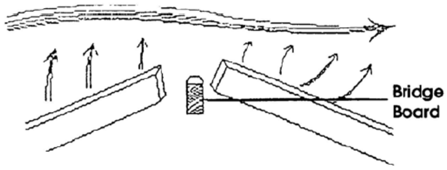


Figure 47

The ridge can be secured by using:

Collar ties - Timbers connecting the rafters. Nail them to the side of the rafters.

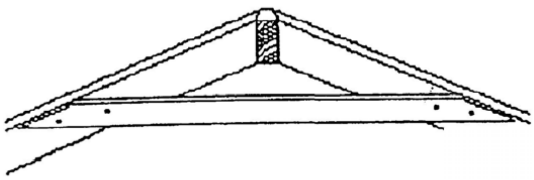


Figure 48

Gussets - Usually made of steel/plywood. This is used at the ridge.

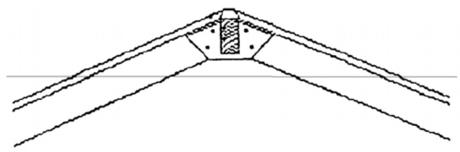


Figure 49

Metal straps over the top of the rafters.

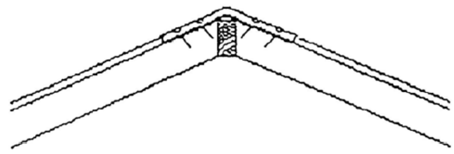


Figure 50

3.6 Reinforce the triangular bracing in the structure

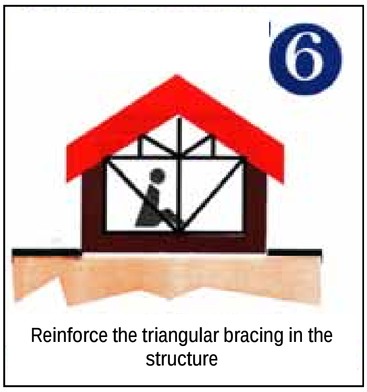


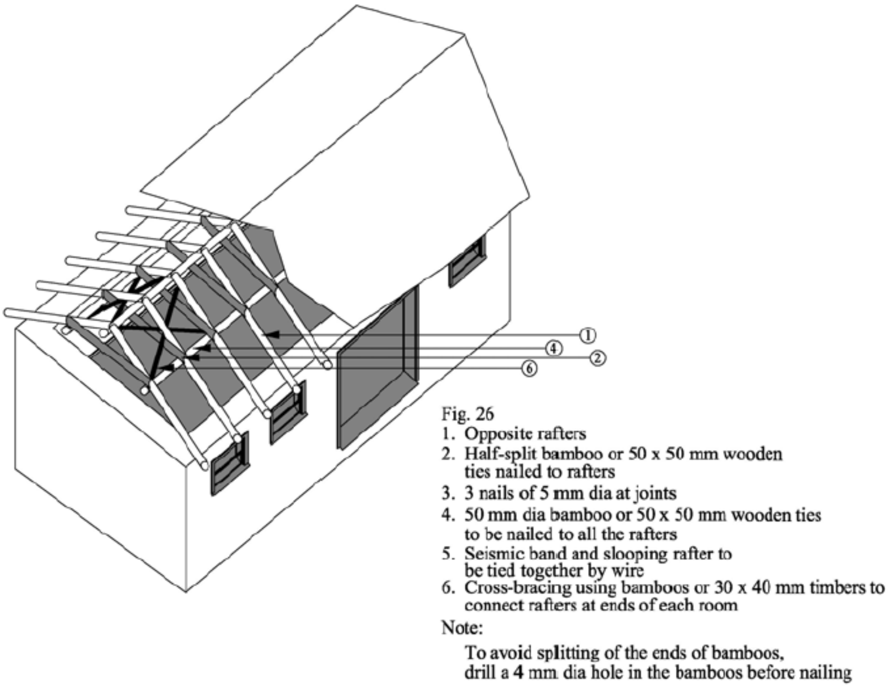
Figure 51

Adequate diagonal or knee bracing should be provided both at the rafter level and the eaves level in a pitched roof. The purlins should be properly anchored at the gable end. It is desirable that at least two bays, one at each end, be braced both in horizontal and vertical plane to provide adequate wind resistance. Where number of bays is more than 5, use additional bracing in every fourth bay.

Enhancing the stiffness of the house by adding the triangular braces.

- Vertical cross braces should be used to reinforce the stiffness between two trussed rafters, or between gable and trussed rafter, between to gables, or between columns.
- Horizontal cross brace should be used at the ceiling level.
- Cross braces are also used in the roofs to stiffen the roof structure.

Below are the cross braces which are often to increase the stiffness of the house.



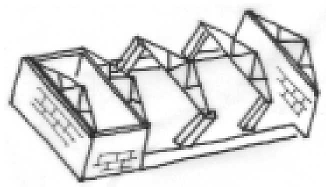
Bracing the raftered roofs

Figure 52

3.6.1 Vertical cross braces

a Increase the stability of trussed rafters

The vertical cross braces are not often used in housing due to the local culture and aesthetic aspect. However, with these braces, the house is much stronger and to some extent can resist the cyclone.



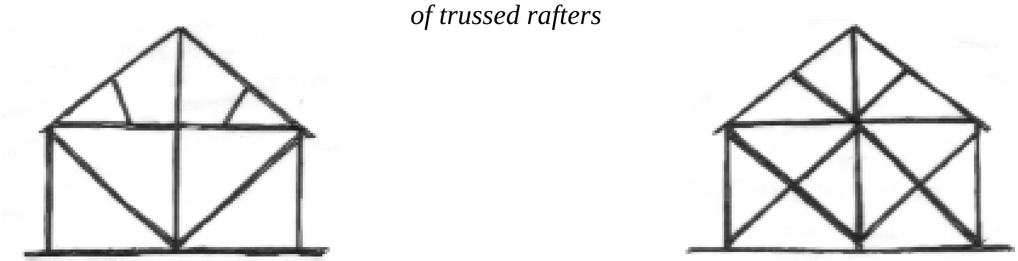
House without vertical cross bracing

b Enhance the stiffness of each component

In order to reduce wind-induced flutter/vibration of the roof in cyclonic regions, it is recommended that all members of the truss and the bracings be connected at the ends by at least two rivets/bolts or welds. Further the cross bracing members by welded/connected at the crossings to reduce vibrations.

- Main frame of the house
- The wall
- In the corner of the house

Vertical cross braces to enhance the stability of trussed rafters



Cross bracing for the main structure of the house

Figure 53

3.6.2 Horizontal cross bracing

In order to enhance the stability of the house, the horizontal cross bracing is used. This bracing is applied at the ceiling level. Due to some aesthetic aspects and the local culture, this bracing is not often practiced. However, the horizontal cross bracing is very important to increase the stiffness of the house.

3.6.3 Cross bracing in the roof

The roofs which are covered by iron sheet, fibrocement tile, thatch, etc beside the horizontal and vertical cross bracings, it needs the cross bracing in the roof to stiffen the entire roof structure.

Cross bracing in the roof

Figure 54

3.7 Make sure the roof covering is attached to the roof structure to prevent it from lifting off

Make sure the roof covering is attached to the roof structure

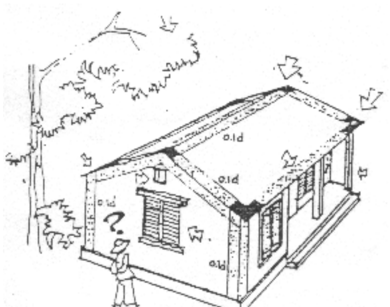
Figure 55

Make sure the roof covering is not lifted off due to:

- The negative pressure above the roof
- The uplift force below the roof in case the doors and windows are broken

The roof is born the direct impacts of the wind force. Both sides of the roof bear different wind pressures: one side bears the pressing force and another side bears the suction pressure. The suction pressure often causes the roof blow off. Cyclone always changes its direction. In case the house has no doors and windows or the openings are broken, the wind force from inside of the house coupled with the suction force from outside cause destructive damage to the roof.

As the corners and the roof edges are zones of higher local wind suctions and the connections of cladding/sheeting to the truss need to be designed for the increased forces. Failure at any one of these locations could lead progressively to complete roof failure. The following precautions are recommended.



Weak parts of the roof need to pay attention

Figure 56

3.7.1 Tile covering

Because of lower dead weight, these may be unable to resist the uplifting force and thus experience heavy damage, particularly during cyclones. Anchoring of roof tiles in R.C. strap beams is recommended for improved cyclone resistance. As alternative to the bands, a cement mortar screed, reinforced with galvanized chicken mesh, may be laid over the high suction areas of the tiled roof.

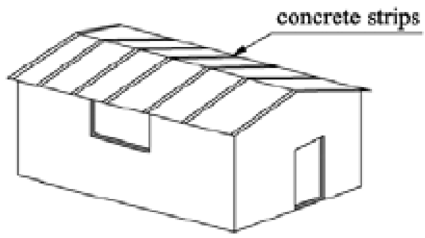
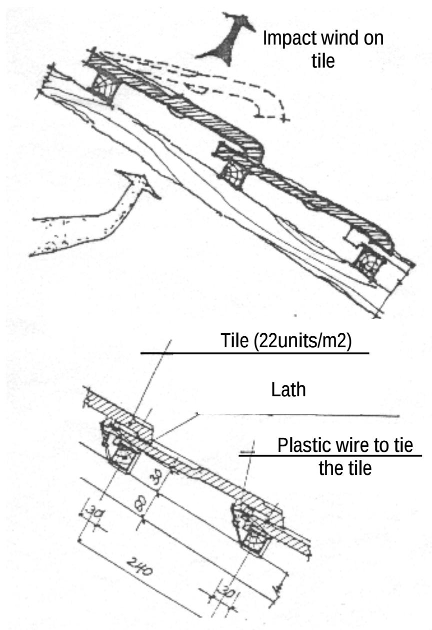


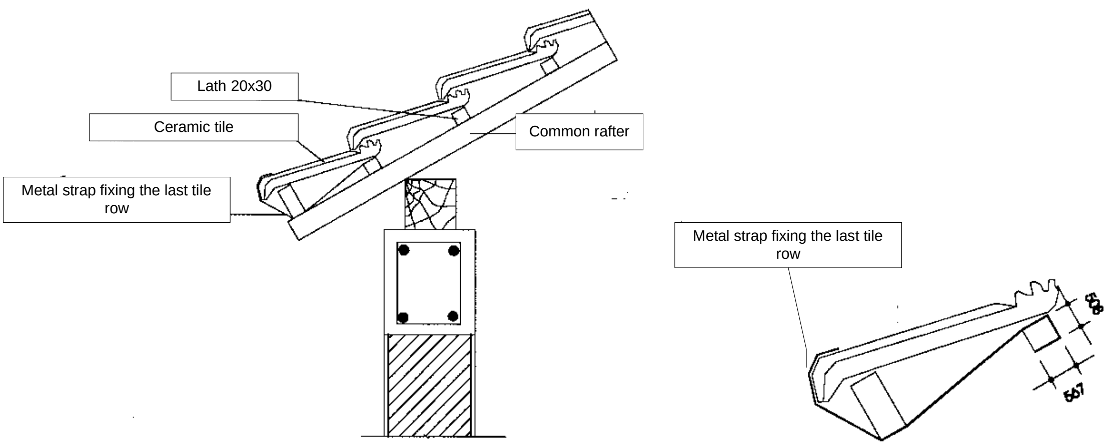
Figure 57

Nowadays, clay tile is often lean against to the lath. Hence, it is often blown off during the cyclone. There are some ways to improve the connection between tiles and roof structure. The tile should have a hole in its bottom so that it can be connected to the lath by plastic wires or use the concrete strips on the clay roofs.



Tile and lath connection

Figure 58

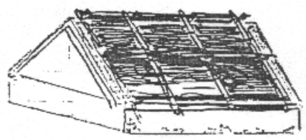


Details of tile and lath connection

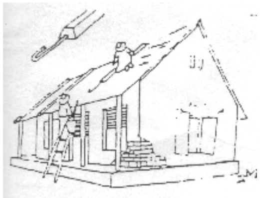
Figure 59

For the existing roof, there are some ways to improve:

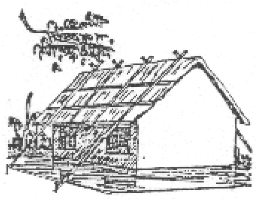
- Use wooden or bamboo frame to put on the roof;
- Use pre-cast concrete bar to put on the roof;
- Use rice straw to put on the roof when there is a typhoon.



Use wooden or bamboo frame to put on the roof



Use pre-casted concrete bar to put on the roof



Tie the roof into the ground

Figure 60

3.7.2 Iron sheet covering

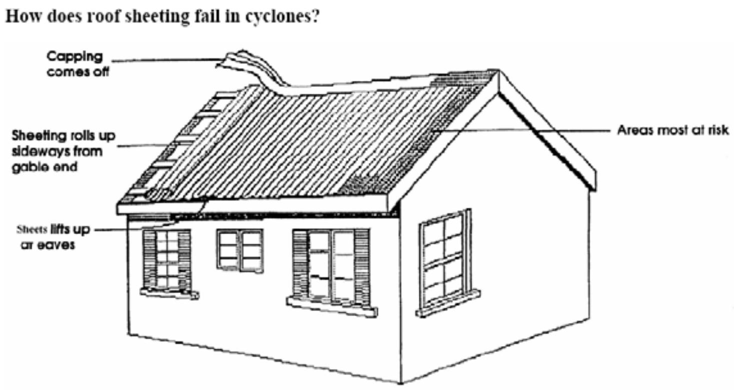
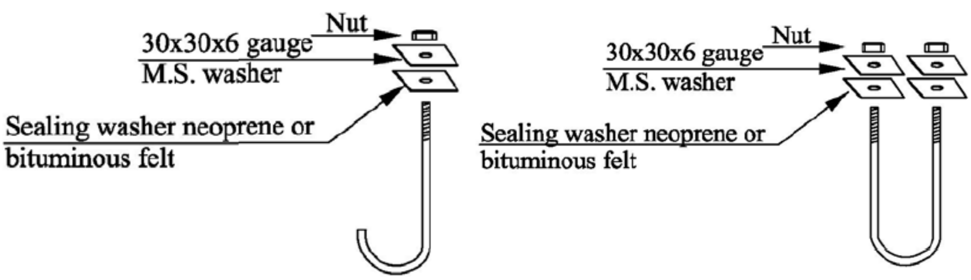


Figure 61

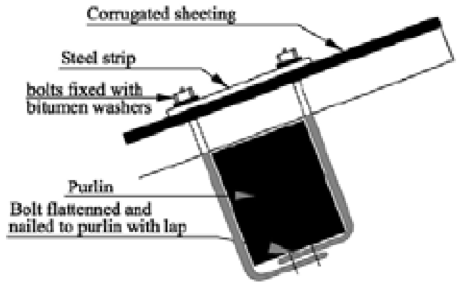
For normal connections, J bolts may be used but for cyclone resistant connections U bolts are recommended. Alternatively a strap may be used at least along edges to fix cladding with the purlins to avoid punching through the sheet. Properly connected M.S. flat can be used as reinforcing band in high suction zones. The corrugated sheeting should be properly overlapped (at least 2 1/2 corrugation) to prevent water from blowing under the seam. Spaces between the sheeting and the wall plate should be closed up to prevent the wind from getting under the sheeting and lifting it. This can be done by nailing a fascia board to the wall plate and rafters.



J bolt – cyclone connection for roof cladding to purlins

U bolt – cyclone connection for roof cladding to purlins

Figure 62



Fixing of corrugated sheeting to purlins with bolts

Figure 63

Traditionally, it is often used nail to fix the iron sheet into the roof structure. However, this fixing is not strong enough to present the sheet from lifting off. It is recommended to use V shape steel bar on the roof to attach the sheet firmly to the purlins.

If the sheeting is too thin or there are too few fittings, the nails or screws may tear through the sheet. Therefore:

- Fix every two corrugation at ridges, eaves and overhangs.
- Fix every three corrugation. Maximum spacing at all other locations or use galvanized iron flats under the fixings.

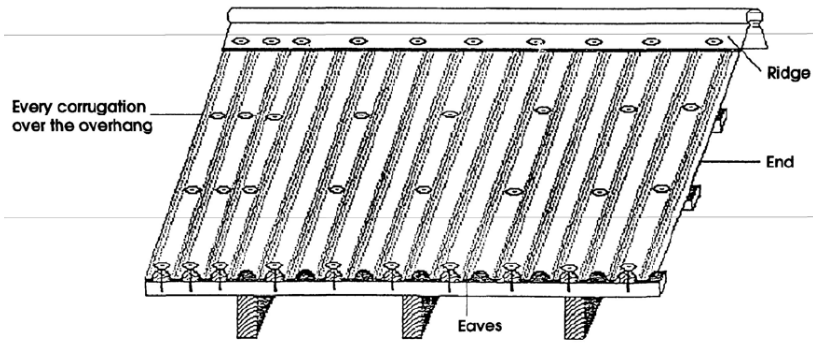
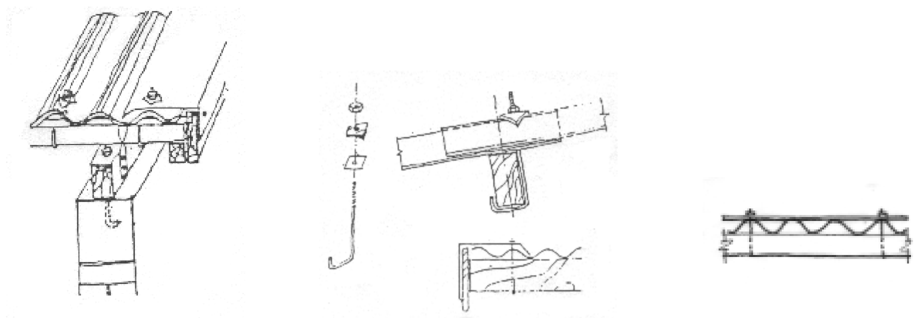


Figure 64



Roof covering attatchment

Figure 65

a. *Fixings for sheeting*

Use fittings with a broad washer or dome head (zinc nail). To use more fixings for each sheet, put in the laths at closer centers and nail closer together.

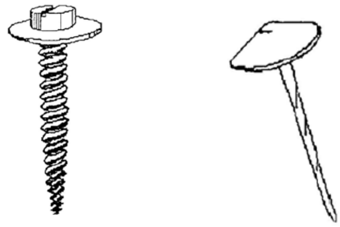


Figure 66

b. *Screws*

- Use proper drive crews for corrugated galvanized roof sheets.
- Be sure that the screws go into the purlins at least fifty mm.
- Use large washers under the screw heads to prevent the roof sheets from tearing when pulled upward by high winds.

c. *Nails*

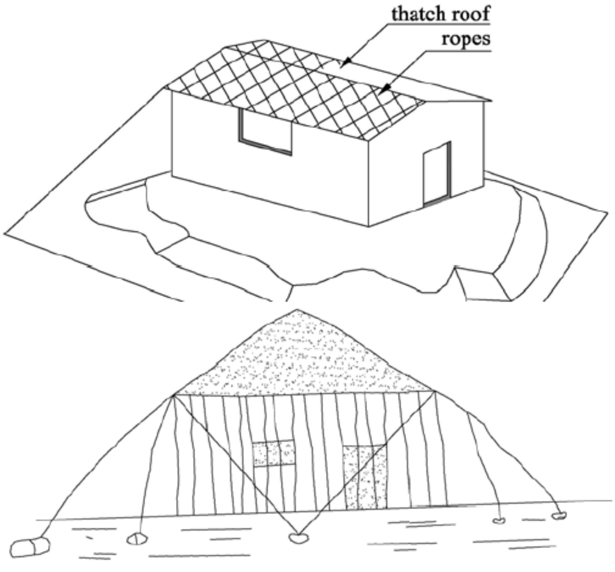
- Nails do not hold as well as screws.
- Use nails with wide heads and long enough to bend over below the lath.
- Galvanized coated nails are better than ordinary wire nails.

d. *Laths spacing and fixing*

- Spacing for laths and number of fixings will vary with the gauge of sheeting used.
- Screws hold better than nails so fewer screws can be used. But the sheeting must be thick or they will tear through.
- Laths should be placed closer together for thin sheets to provide space for extra fixings.

3.7.3 Thatch covering

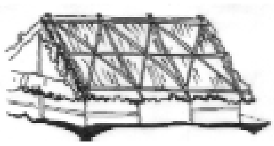
Thatched roof should be properly tied down to wooden framing underneath by using organic or nylon ropes in diagonal pattern. The spacing of rope should be kept 450 mm or less so as to hold down the thatch length. For connecting the wooden members, use of non-corrodible fixtures should be made. If non-metallic elements are used, these may need frequent replacement. After a cyclone warning is received, all the lighter roofs should be held down by a rope net and properly anchored to ground.



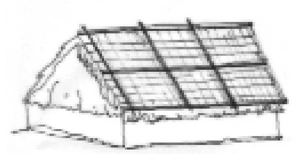
Rope tie-backs for weak structures

Figure 67

Some regions, bamboo frame or bamboo wattle combined with bamboo frame are used to protect the thatch roof.



a. Proctect the roof by bamboo frame

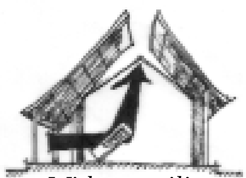


b. Protect the roof by bamboo wattle and bamboo frame

Figure 68

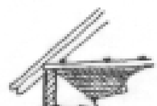
3.7.4 Protect the roof covering by the ceiling

The sloped roof (ceramic tile, iron sheet, fibrocement tile) should have the ceiling. The ceiling will increase the stiffness of the house and protect the roof covering from lifting off. It also reduces the temperature of the house in hot season and beautifies the house.



Without ceiling

With ceiling



Plywood ceiling

Figure 69

3.8 Match opposing openings

Wind generating opening on the windward side during a cyclone will increase the pressure on the internal surfaces. This pressure, in combination with the external suction, may be sufficient to cause the roof to blow off and the walls to explode. Therefore, ensure the opposing openings have the approximative size because during a cyclone an opening may suddenly occur on the windward side of the house, and the internal pressure, which builds up as a result may be relieved by opposing opening on the leeward side.

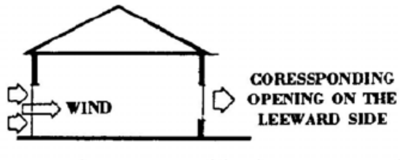


Figure 70

3.9 Use doors and windows that can be closed

Figure 71

Openings in general are areas of weakness and stress concentration, but needed essentially for light and ventilation. The following are recommended in respect of openings.

Avoid openings, which cannot be securely closed during a cyclone. Where openings are already in existence, cyclone shutters should be provided

Openings in load bearing walls should not be within a distance of h/6 from inner corner for the purpose of providing lateral support to cross walls, where ‘h’ is the storey height up to eave level.

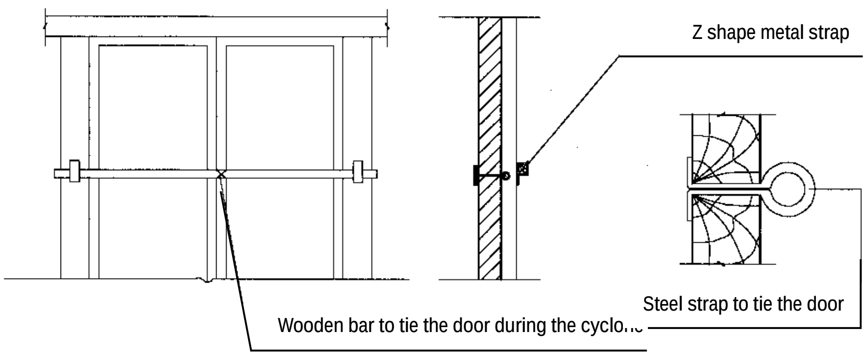
Openings just below roof level be avoided except that two small vents without shutter should be provided in opposite walls to prevent suffocation in case room gets filled with water and people may try to climb up on lofts or pegs.

Since the failure of any door or window on the windward side may lead to adverse uplift pressures under roof, the openings should have strong holdfasts as well as closing/locking arrangement.

Make sure all doors and windows can be closed firmly. This is an important point to reduce the pressing force, which often causes the roof lifting off. Apart from roofs, the elements requiring the most attention are windows and doors. Sadly, these are often neglected. In rural areas, many houses do not have enough doors and windows, or if they have the doors and windows are too weak to bear the typhoon due to some reasons:

- Doors and windows is the last priority when building the house because of financial constrains
- The connecting components are weak
- Temporary doors and windows made by bamboo wattle

Those problems intensify the wind pressure on the roof and on the walls.



Details of door and window components

Figure 72

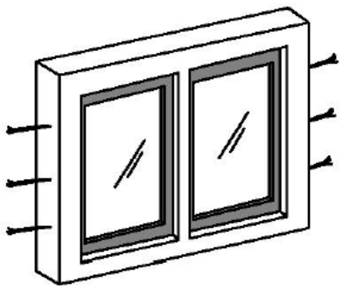


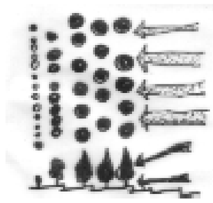
Figure 73

3.10 Plant tree around the house as wind breaks

Plant tree around the house as windbreaks

Figure 74

As mentioned earlier in this chapter, a row of trees planted upwind will act as a shield. The influence of such a shield will be over a limited distance, only for 8 – 10 times the height of the trees. A tree broken close to the house may damage the house also hence distance of tree from the house may be kept 1.5 times the height of the tree. Zigzag tree planting will act as a good shield to protect the house.



Zigzag tree planning

Figure 75

If the trees are too thick, they will create the whirlwind causing negative impacts on housing. Trees should be planted with a distance that allows wind pass through so that the whirlwind will not be formed. Zigzag tree planting with many rows can meet this condition. Tree planting will have its specific arrangement depending upon the surrounding condition. Remember to trim the tree near the house to avoid the damage caused by tree broken.

Use trees as windbreak

Figure 76

4 BASIC PRINCIPLES OF RESIDENTIAL DEVELOPMENT PLANNING IN THE CYCLONE PRONE AREAS

4.1 Vulnerable communities

The vulnerability of a human settlement to a cyclone is determined by its sitting, the probability that a cyclone will occur, and the degree to which its structures can be damaged by it. Buildings are considered vulnerable if they cannot withstand the forces of high winds. Generally those most vulnerable to cyclones are lightweight structures with wood frames, especially older buildings where wood has deteriorated and weakened the walls. Houses made of unreinforced or poorly constructed concrete block are also vulnerable.

Urban and rural communities on low islands or in unprotected, low- lying coastal areas or river floodplains are considered vulnerable to cyclones. Furthermore, the degree of exposure of land and buildings will affect the velocity of the cyclone wind at ground level, with open country, seashore areas and rolling plains being the most vulnerable. Certain settlement patterns may create a "funnel effect" that increases the wind speed between buildings, leading to even greater damage.

4.2 Essential requirements for residential areas

During very high velocity winds, the coastal areas suffer due to storm surge where huge loss of property takes place. Site selection should avoid areas likely to be submerged. It is desirable to locate the site such that it is at least 500m from the shore and 5m above Mean Sea Level

The sites need to be close to the present settlement. It should preferably be within a distance of one km from the present settlement so as to facilitate the fishers to carry out their economic activities easily.

Terrain category and topography of the site should be assessed and based on these correct orientations of the buildings should be finalized. The area behind a mound or a hillock or behind casuarinas plantation should be preferred in order to provide natural shielding

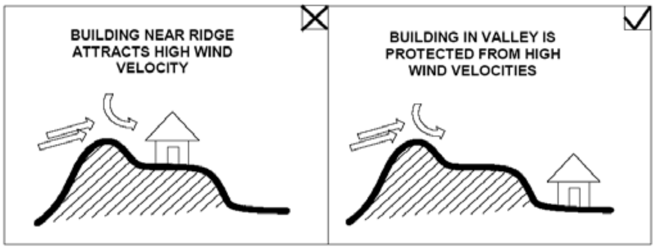
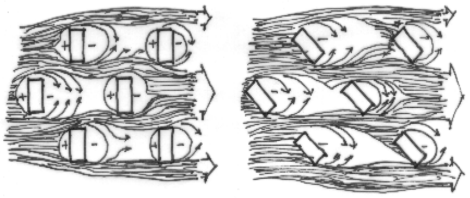
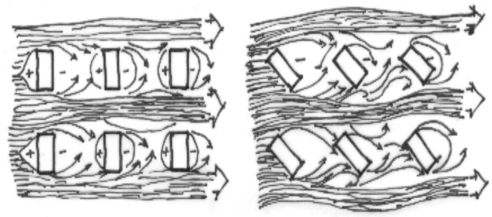


Figure 77

In case of construction of group of buildings, a cluster arrangement can be followed in preference to zigzag planning to avoid winds.



Zig-zag planning avoids wind



Row planning creates wind

Figure 78

The buildings should be oriented in such a manner that the shorter span length of the wall faces the sea

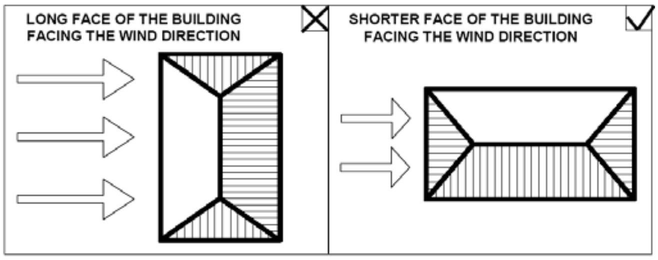


Figure 79

4.3 Considerations in residential planning in cyclone prone areas

Housing needs to be adapted to the local conditions, and resistant to the strong winds

Make sure all families can easily access to safe shelter during the strong cyclone

Each residential cluster needs to have a strong public building such as school, climatic center, which can be accommodate evacuee during the storms.

Try to use local materials and local knowledge in housing construction, and apply cyclone resistant techniques for construction.

Improve surrounding environment such as planting tree, forest, mangrove, which can be used as a shield to protect the residential areas.

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