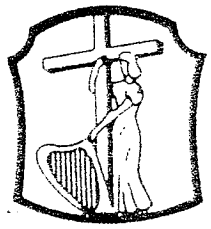
Government of Montserrat



Hurricane - Resistant Construction Manual

Are You Well Connected?

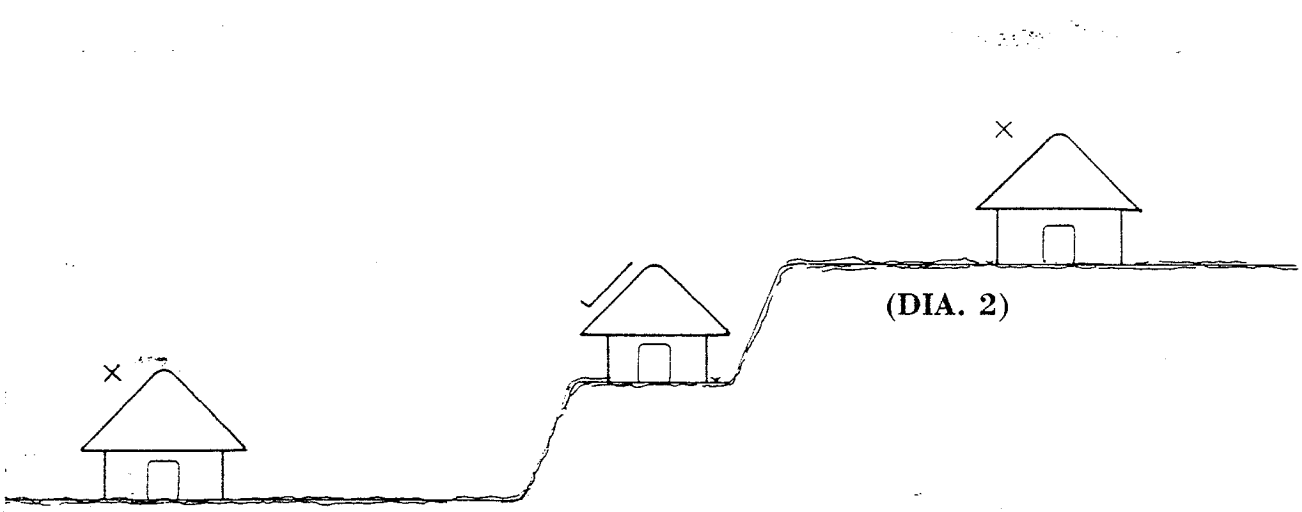
United Nations Centre For Human Settlements
United Nations Development Programme

1. SITE SELECTION

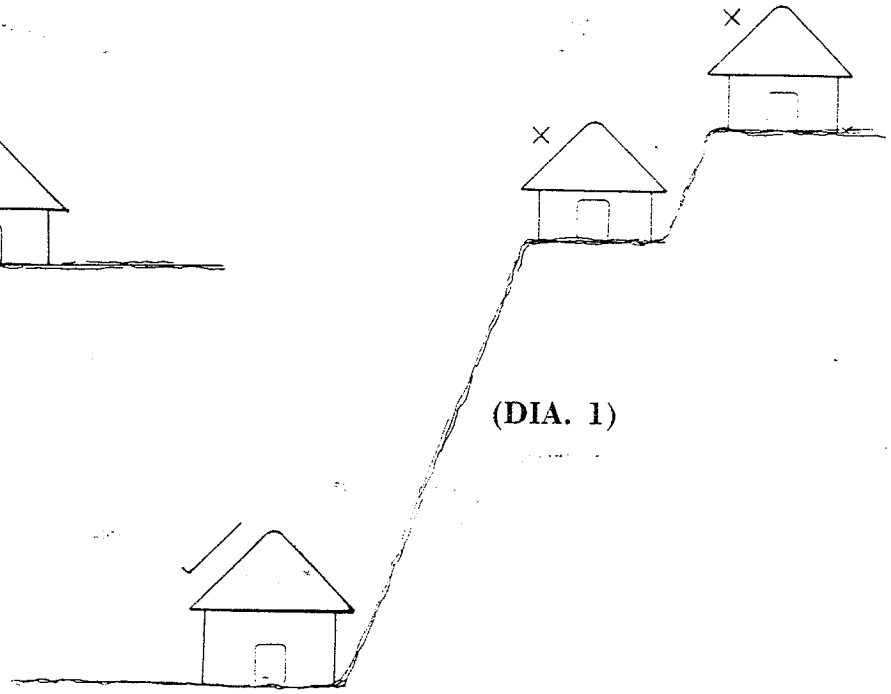
- Try to select a safe site.

Avoid:

1. Tops of hills because they are less protected. (DIA. 1)
2. Large exposed level areas whether High or Low because they are less protected. (DIA. 2)
3. Ghauts or sloped valleys because they act as funnels which increase the speed of the wind.
4. Sites adjacent to structures or large trees which are not likely to withstand hurricane force winds.
5. Sites in areas where flooding and landslides are likely.



(DIA. 2)



(DIA. 1)

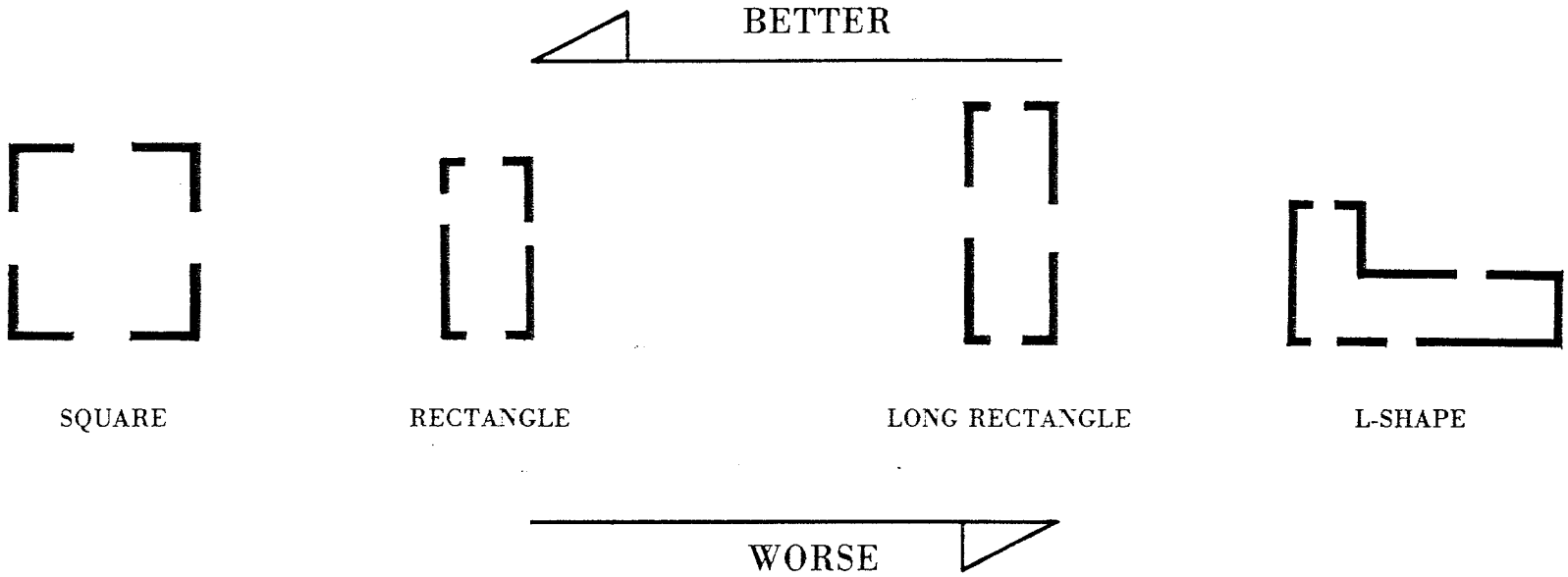
- If the home owner has no choice other than to build on one of the above indentified sites, he/she is strongly advised to observe the recommendations given in this Manual.

2. SHAPE OF THE HOUSE

A: Walls

(i) Plan Forms

- The most effective plan form for wind resistance is the square, followed by the rectangle, then the long rectangle, with the L-shape being the least effective. Most houses are rectangular and the best length to width ratio is 3:1 or less.

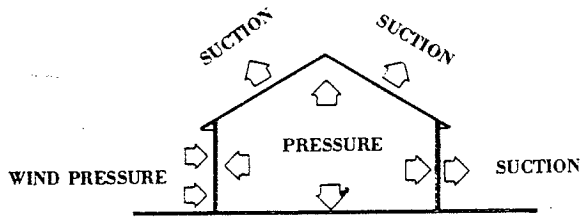


PLAN OF WALLS

- The L-shape is vulnerable to high winds, because it channels the wind into the junction between the two wings. This may cause an increase in the wind pressure on the junction which maybe sufficient to lead to failure of the joint.

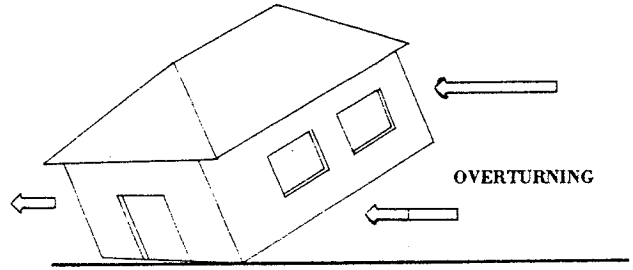
(ii) Failure of the Wall

Wind forces on the walls of the house may produce failure.

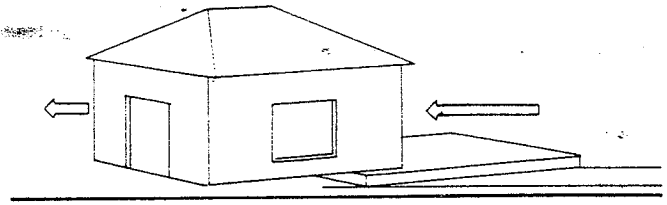


- Wind striking a building produces pressure which pushes against the building, on the windward side, and suction which pulls the building on the leeward side and the roof.

- If no air enters the building, then there is pressure inside which is pushing against the walls and the roof.



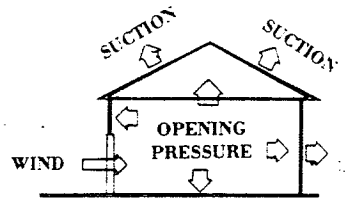
- Overturning is another problem for light structures. This occurs when the weight of the house is insufficient to resist the tendency of the house to be blown over.



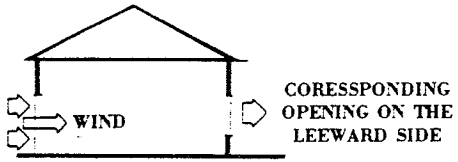
PUSH AND PULL FORCES MAY CAUSE THE HOUSE TO SLIDE OFF ITS SUPPORT.

- Failure may occur when the external pressure and suction on the walls combine to push and pull the building off the foundation.

- If the house is not tied down to the foundation, then it may slide off its supports.

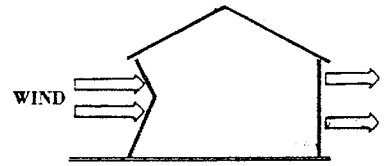


- Wind penetrating an opening on the windward side during a hurricane will increase the pressure on the internal surfaces. This pressure, in combination with the external suction, may be suf ficient to cause the roof to blow off and the walls to explode.



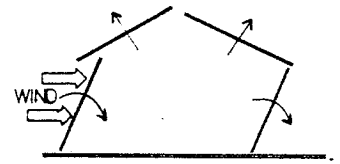
- During a hurricane an opening may suddenly occur on the windward side of the house.

- The internal pressure which builds up as a result may be relieved by providing a corresponding opening on the leeward side.



WINDWARD FACE OF THE BUILDING COLLAPSES UNDER PRESSURE OF WINDFORCE

- Another mode of failure occurs when the windward side of th house collapses under the pressure of the wind.



RACKING

COLLAPSE STARTS AT THE ROOF
BUILDING LEANING IN WIND
DIRECTION

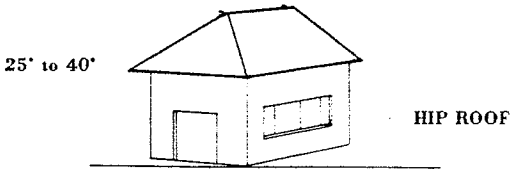
- If the building is not securely tied to its foundations, and the walls cannot resist to push/pull forces the house tends to collapse starting at the roof with the building leaning in the direction o the wind.

All modes of failure can be avoided by bracing and reinforcing the concrete block walls.

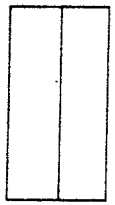
B: Roof

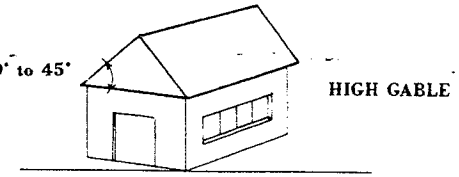
The shape of the roof will influence the magnitude of the wind load on the structure.

(i) **Roof Shape**
(ii) **Failure of the Roof**

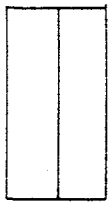


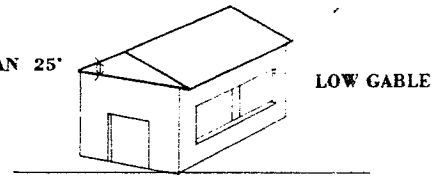
Experience and experiment have shown that the hip roof with the pitch in 25° to 40° range has the best record of wind resistance.



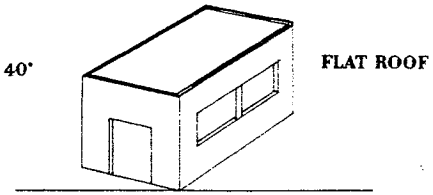


The next best roof shape is the high gable with a pitch in the 30° to 45° range.

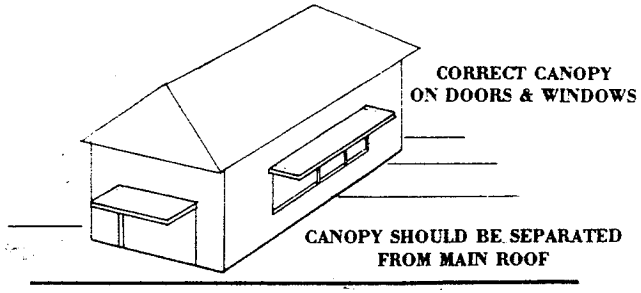




Following the high gable is the low gable with a pitch of less than 25°.



The flat roof is the least effective roof type for wind resistance.



- where a canopy or overhang is desired, it should be separated from the main roof. The canopy may then suffer wind damage without affecting the main roof structure.

(i) **Failure of the Roof**

Windstorm damage often starts with roof failure, which may occur by cladding blowing off and/or the roof lifting off from its supporting walls.

3. DESIGN CONSIDERATIONS

A. General

In the previous sections, certain design features which may increase the wind resistance of the structure and areas which are particularly exposed to wind damage have been identified.
It is therefore necessary during design to incorporate these features and to strengthen the areas where wind damage is likely to occur.

B. Summary

1. Avoid a low pitched roof, use a hip roof or a high pitched gable roof.
2. Avoid overhanging roofs. If overhangs or canopies are desired, they should be separated from the main roof structure.
3. Avoid openings which cannot be securely closed during a hurricane. Where such openings are already in existence, hurricane shutters should be provided.
4. Best plan shape for wind resistance is a square or rectangle with length to width ratio no more than 3:1.

4. CONSTRUCTION TECHNIQUES

A. Foundation

The functions of the foundations are

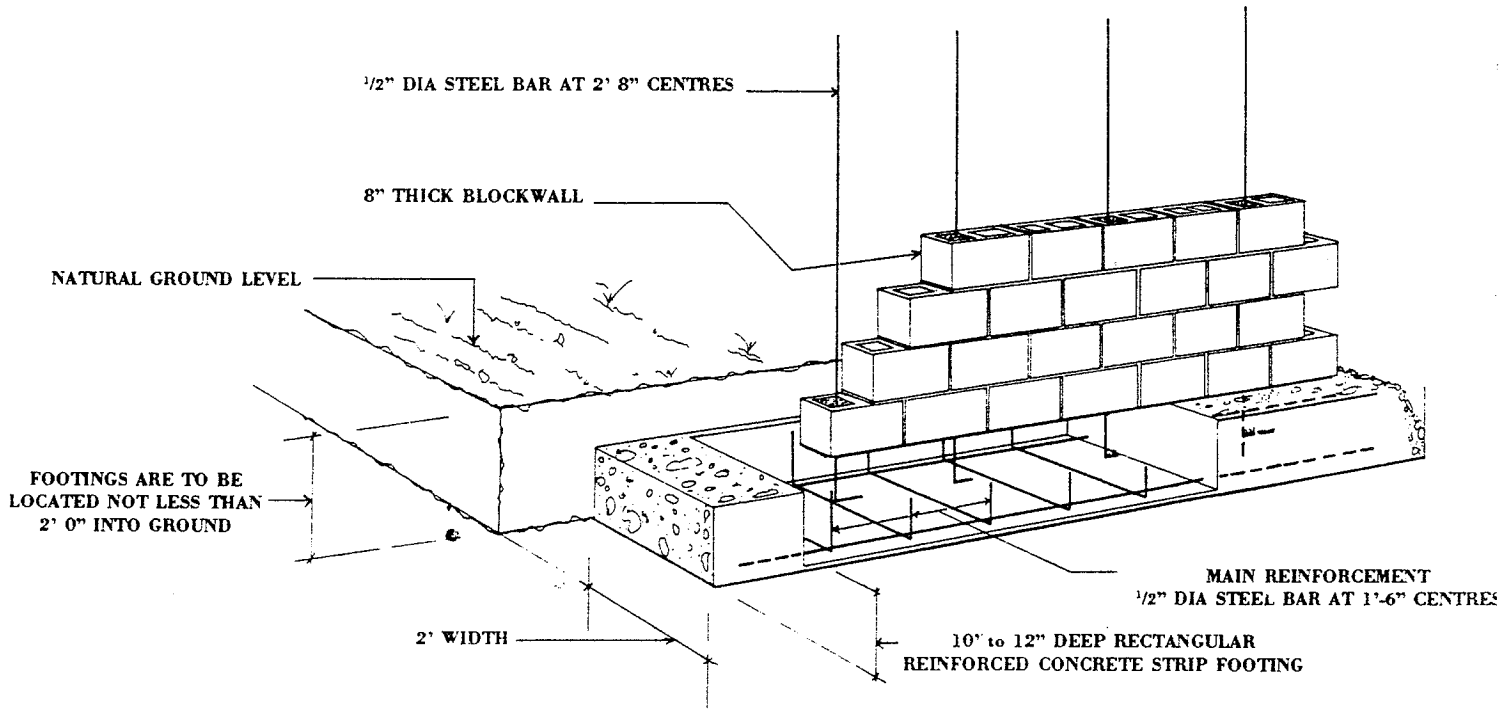
- 1. To securely anchor the house to the ground to prevent wind forces from lifting the entire building or blowing it over.

- 2. To transmit the building loads to the ground.
Foundations should be securely connected to the rest of the structure and located not less than 2 foot into the ground on firm strata.

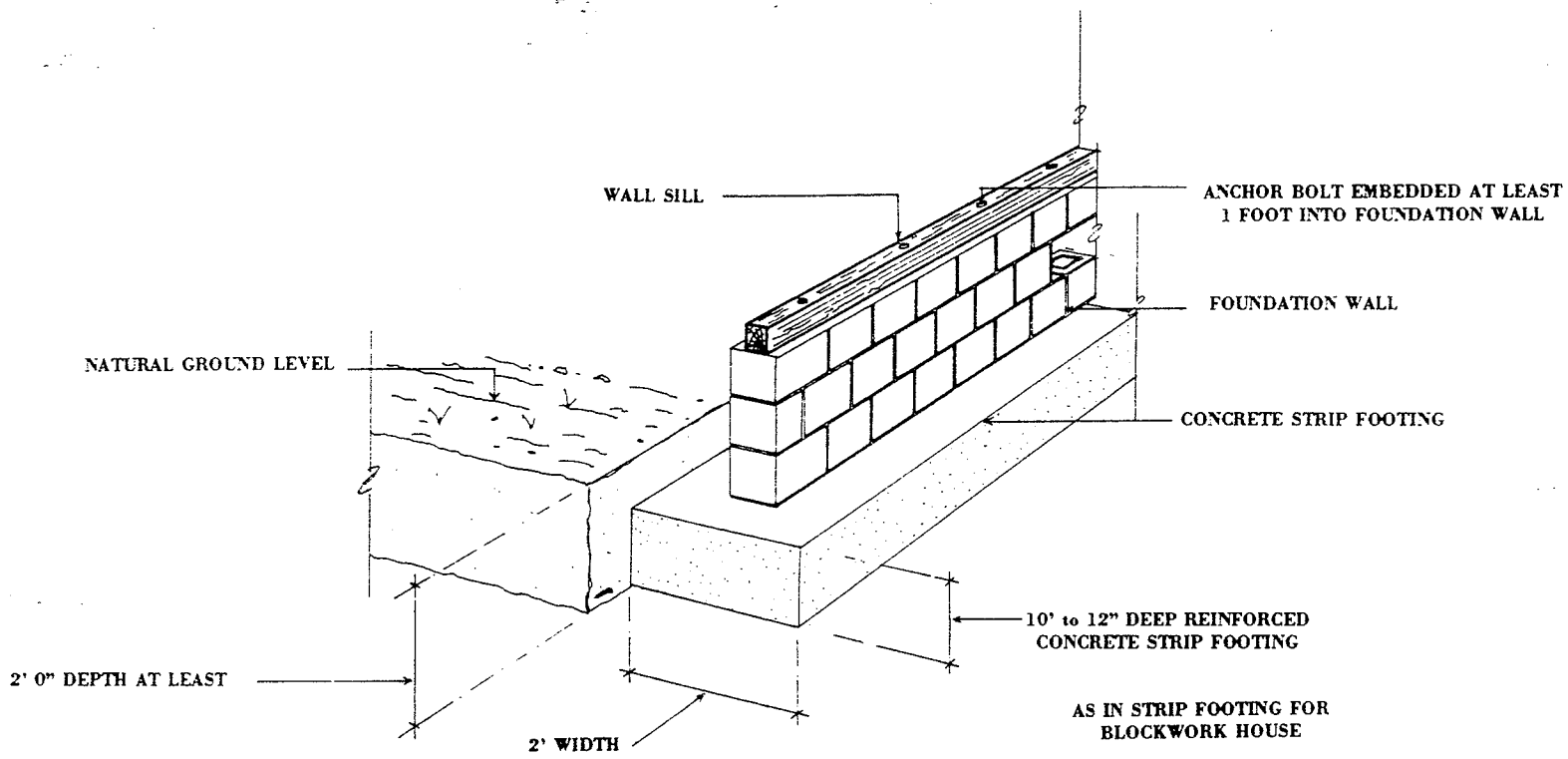
The foundation for blockwall construction is usually a continuous rectangular reinforced concrete strip footing.

The blockwalls which are then built off this footing contain vertical reinforcement which is anchored into the footing.

STRIP FOOTING FOR CONCRETE BLOCKWORK HOUSE



Timber houses may be anchored to the ground by casting a similar strip footing and adding three to six courses of blockwork up to the proposed ground floor level, and then fixing the timber structure to this foundation.



STRIP FOOTING FOR WOODEN HOUSE

B. Ground Floor

To safeguard against flooding the ground floor should be at least 60 cm/2 ft above the natural ground level.

(i) **Concrete Floor**

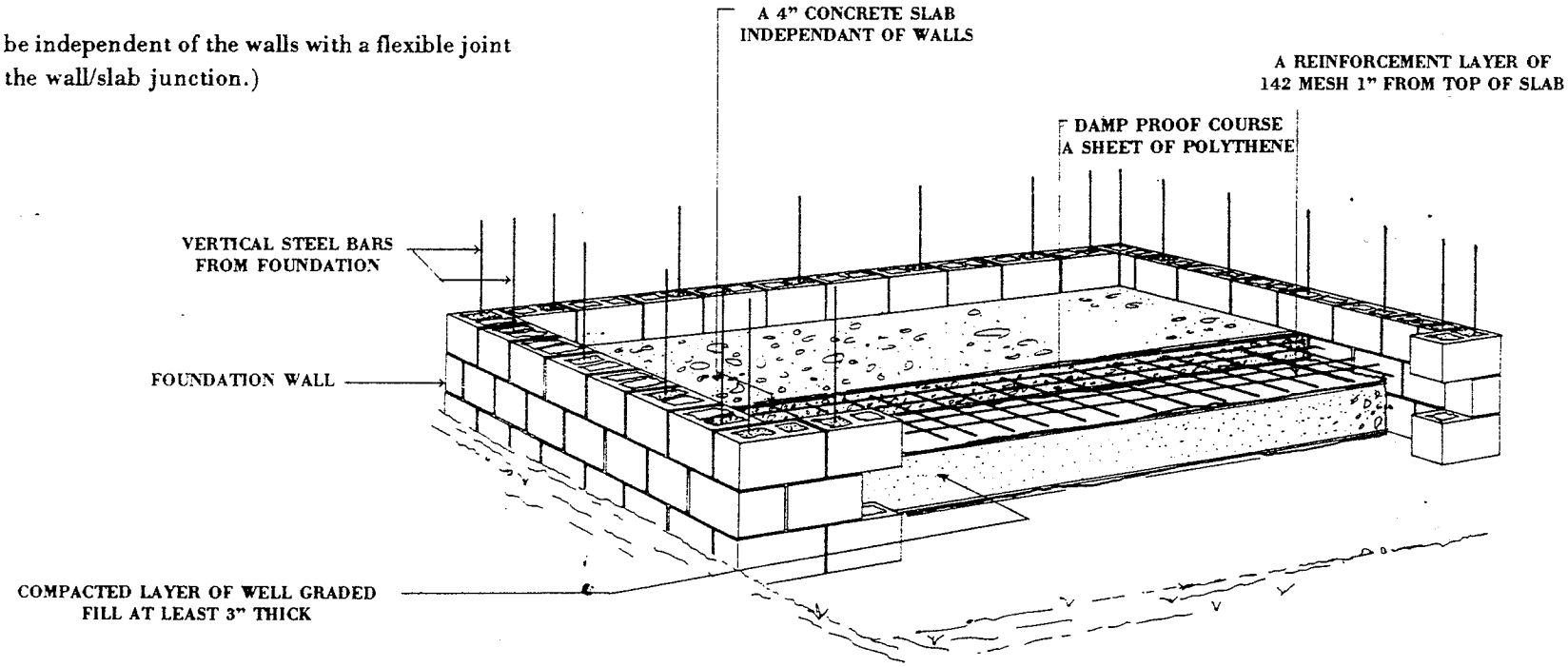
(a) Excavate topsoil and clayey material and replace with compacted well graded fill at least 3 ft thick.

(b) Provide a damp proof course (a sheet of polythene) on the compacted fill.

(c) Cast a 4" thick concrete slab reinforced with a layer of A142 welded wire mesh placed 1" below the top of the slab.

(d) The concrete slab to be independent of the walls with a flexible joint or an open space at the wall/slab junction.)

CONCRETE GROUND FLOOR

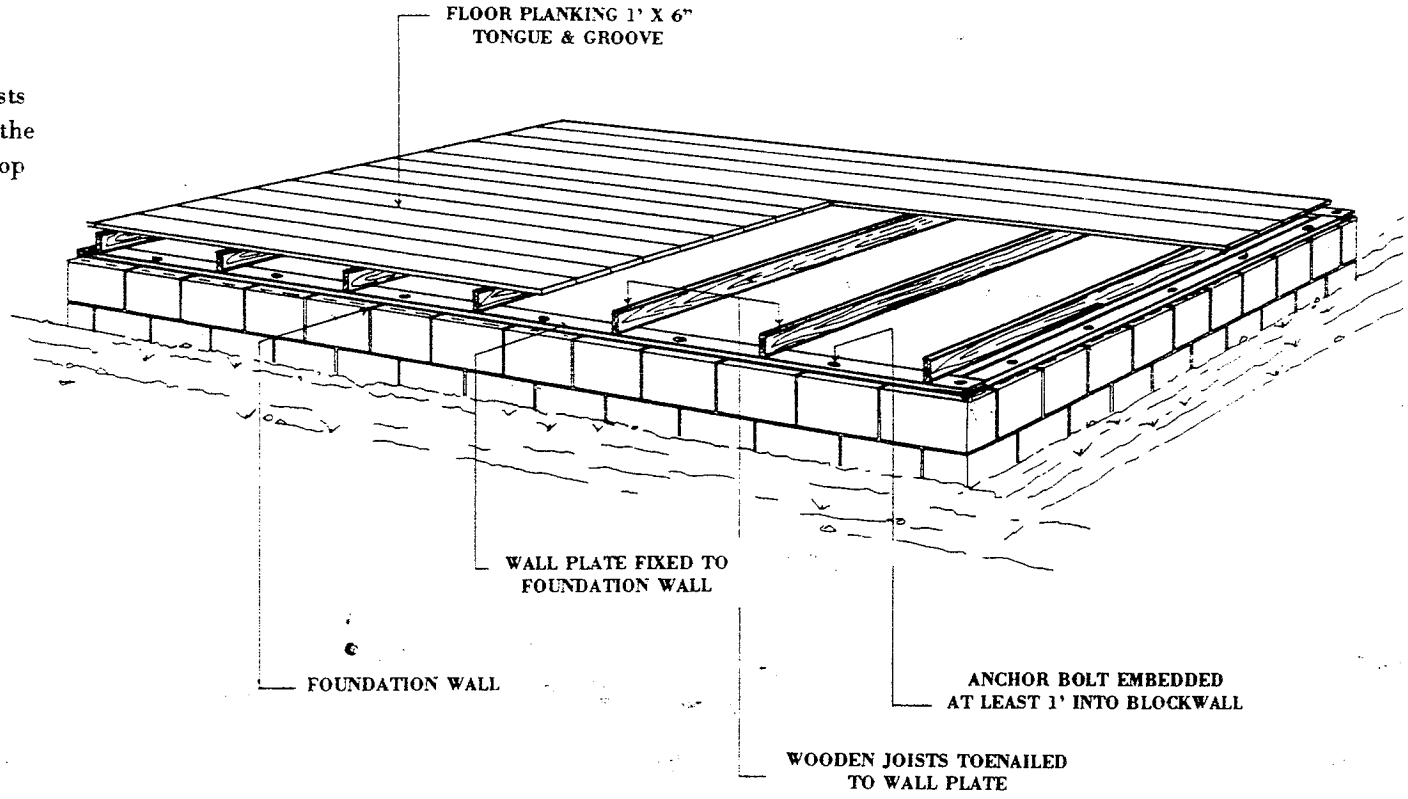


(ii) **Wooden Floor**

- bolt 4" x 4" wall plate (wooden cill) to foundation wall with 1/2" diameter bolts no more than 6 ft apart and embedded at least 1 ft into the wall with concrete poured into the blocks.
- wooden joists are spiked or toenailed to the wall plate.
- 1 x 6" tongue and groove closeboarding is nailed to the joists.
- The following are recommended sizes of pitch pine joists at 2 ft centres for the given span range.

SPAN RANGE	JOIST
6' - 8'	2" x 6"
8' - 10'	2" x 8"
10' - 14'	3" x 8"
14' - 18'	3" x 12"

- At the wall plate the space between the joists should be blocked by a timber member of the same depth as the joist to provide a fire stop and to hold the joists in position.

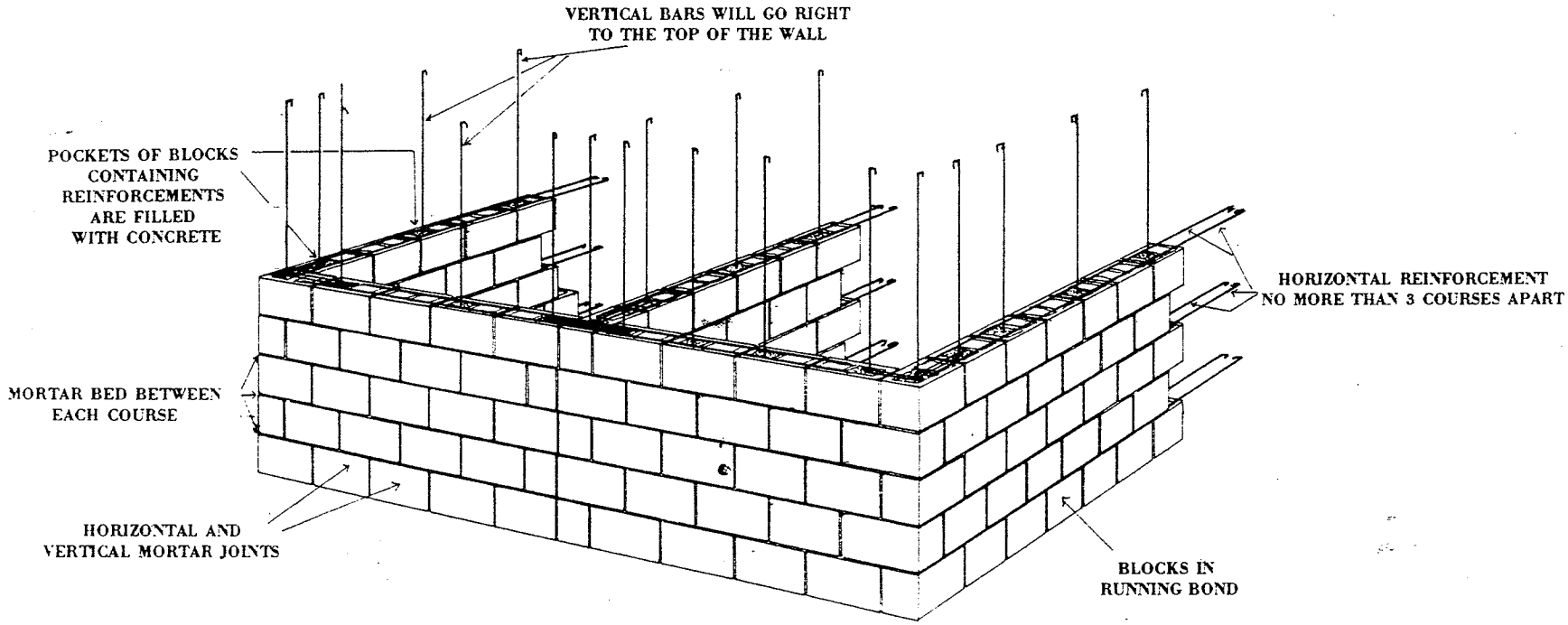


C. Walls

(i) **Concrete Blockwork Walls**

- starter bars coming out of the foundation will tie the wall to the foundation.
- lay blocks so that these starter bars come out through block pockets. For earthquakes the recommended minimum vertical reinforcement is 3/8" diameter bars at 32" centres, this will provide adequate resistance to hurricanes. As more courses are laid you must add more lengths of steel to overlap for at least 2" with starter bars.
- These lengths of steel will go right to the top of the walls.
- pockets of blocks containing reinforcement are to be filled with concrete.
- as each course of blocks is laid, it must be set into a 1:3 mortar bed placed on the last course, mortaris also required on the sides of the blocks to form the vertical joints. Mortar joints should be 3/8" wide.
- galvanized horizontal reinforcement, Dur-O-Wal or Brickforce, should be laid after every third course. (Two 1/4" diameter bars are often used, but they are likely to rust in the thin mortar joints.).
- horizontal reinforcement increase the resistance of the wall to hurricane force winds (and to earthquakes).
- vertical bars are required at all junctions and window and door openings.
- blockwalls should be constructed in running bond rather than stacked bond.

CONCRETE BLOCK WALL

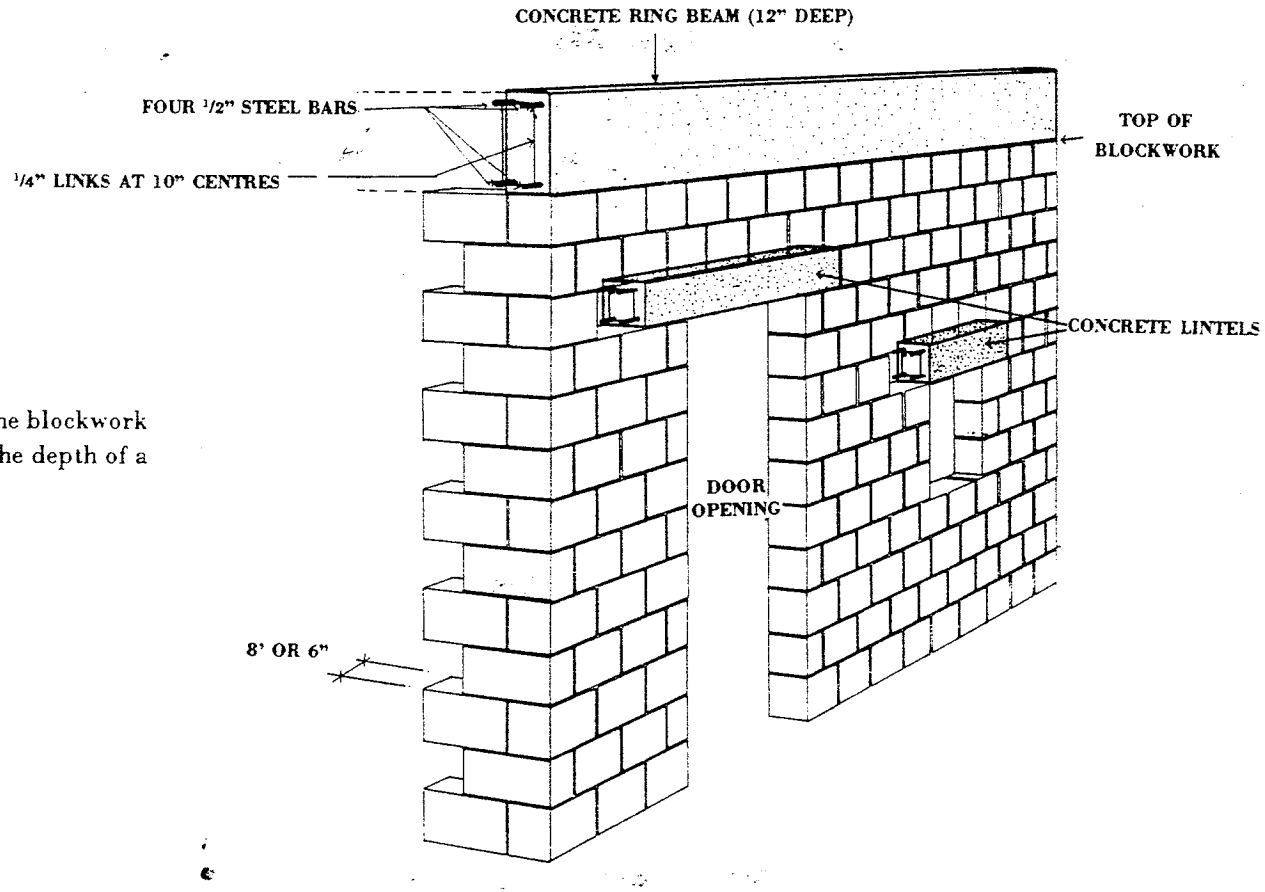


* Rind Beams

- At the roof level a reinforced concrete ring beam (or belt beam) is provided to tie the walls together and to provide a structural support forthe roof. This beam is usually 12" deep by the width of the wall - 8" or 6", and reinforced with either four or two 1/2" diameter bars (depending on the width) with 1/4" diameter links at 10" centres.

* Concrete Lintels:

- Are required over window and door openings to support the blockwork which is above the opening. Lintels are usually 8" deep (the depth of a block) and 8" or 6" wide (the width of the wall).

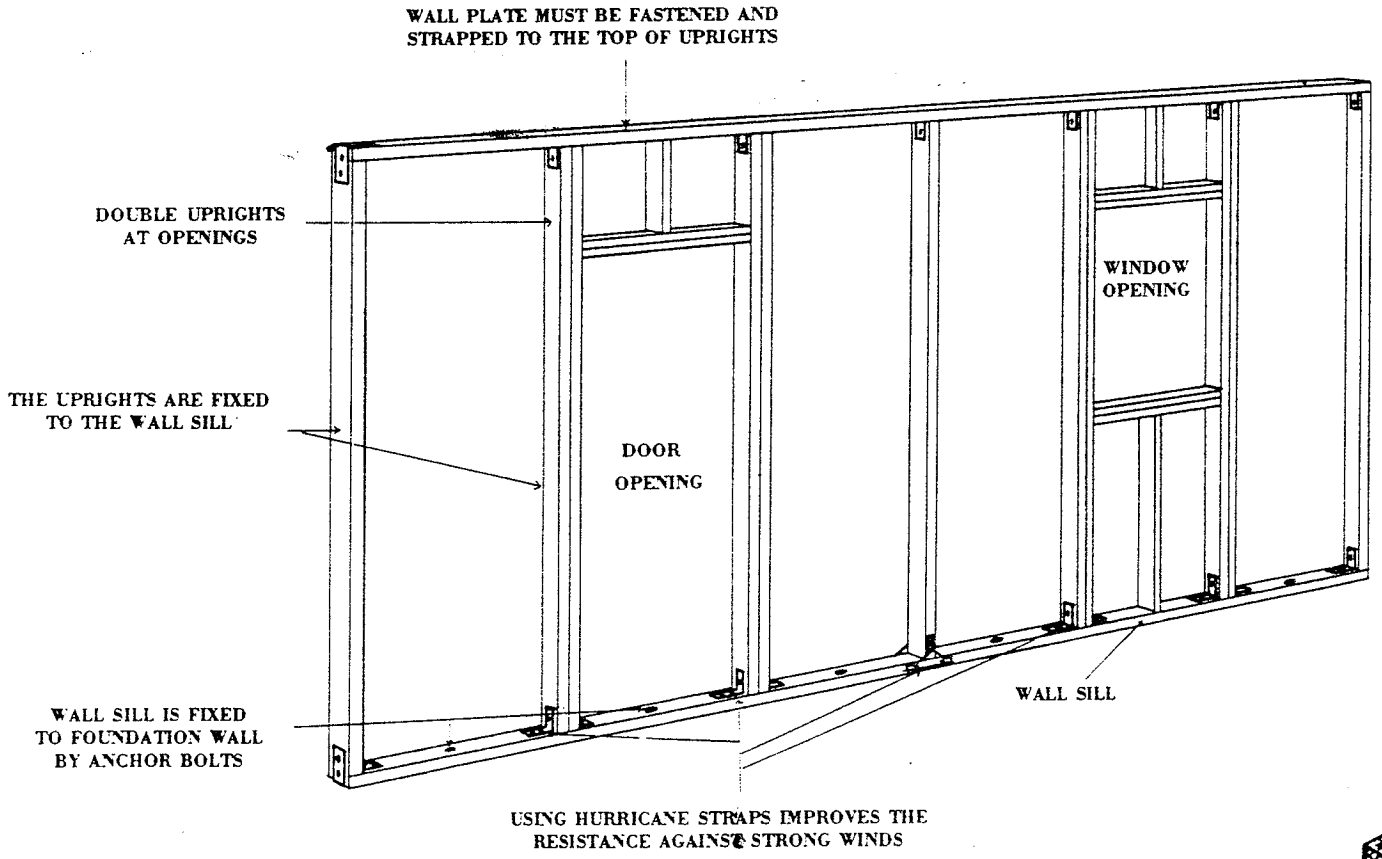


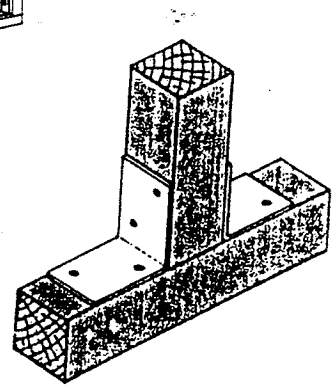
CONCRETE BLOCK WALL

(ii) Wooden Walls

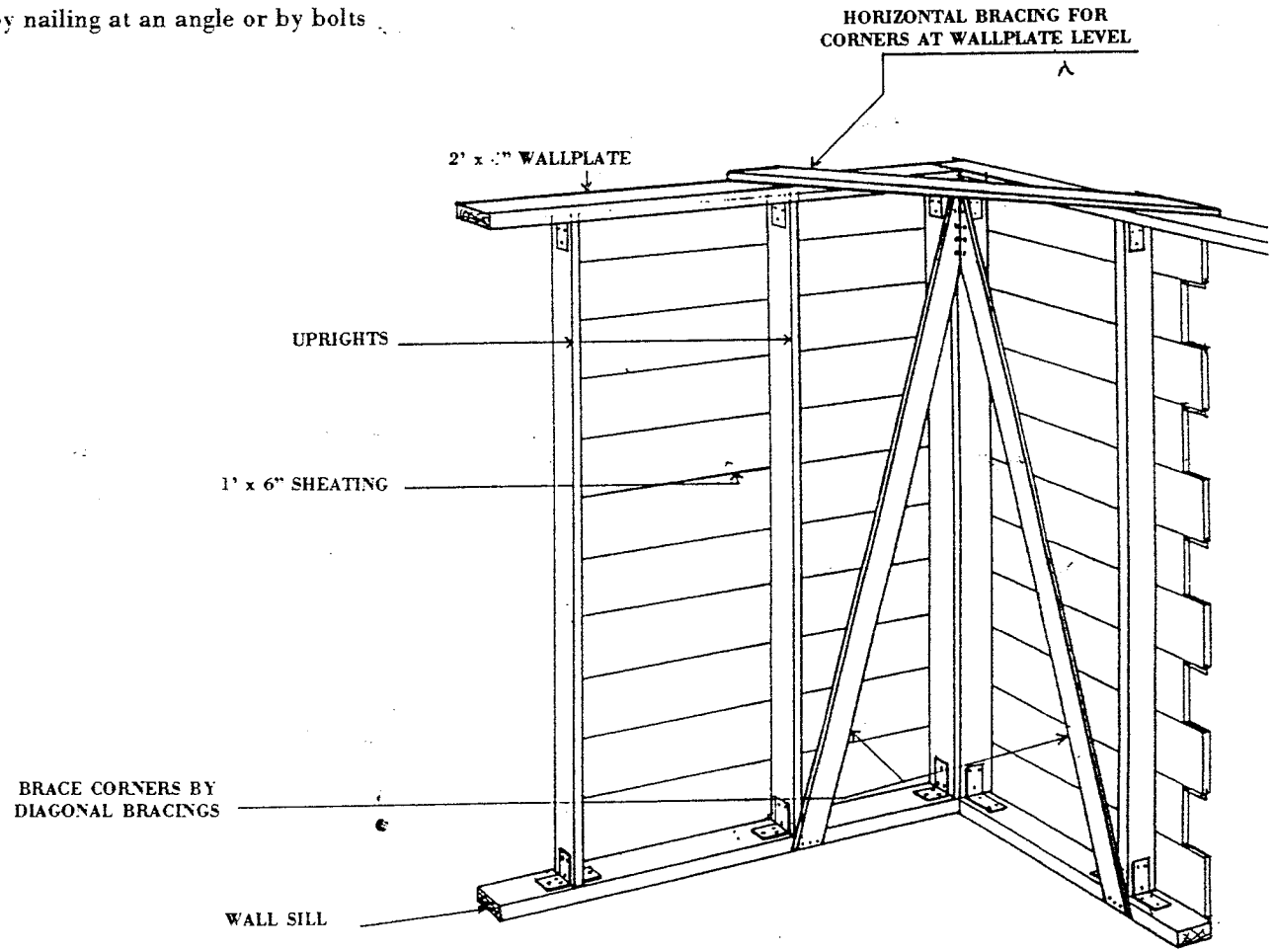
- The uprights (or posts) are fixed to the wall cill which is bolted to the foundation wall.
- Using metal straps with nails improves the hurricane resistance of timber houses.

WOODEN WALL





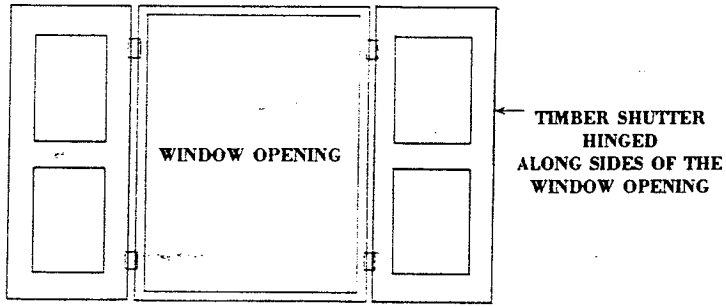
- brace all corners by diagonally in order to resist the tendency of the house to come apart a the corners as a result of unequal forces on two adjacent sides.
- Additional bracing should be provided at the wall plate level. For wooden houses the wall plate must be fastened and strapped to the top of the uprights, using hurricane straps.
- sheathing is the set of boards attached to the uprights to form a completed wall. They must be attached in such a way as to make it difficult for them to be removed, this could be done either by nailing at an angle or by bolts and cleats.



D. Openings

- Generally doors and windows should be as far as possible from the corners of the buildings as as not to weaken the walls significantly.
- In blockwalls doors and window openings should be reinforced with a 10mm diameter bar on each side of the opening.

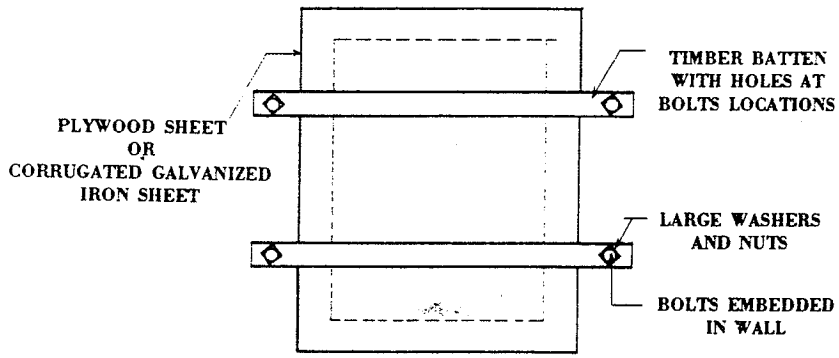
PERMANENT SHUTTERS



E. Shutters

- glass windows and doors should be protected by shutters to secure them during a hurricane.
- shutters maybe divided into two types:
  1. Permanent Shutters:-
  - these may be mounted on hinges on the exterior of the opening with provision for closing and securing them from either inside or outside of the building.
  2. Removable Shutters:-
  - these should be designed so that they can be quickly and easily put in position and secured by one or two persons.
  - bolts should either be galvanized or painted and greased to prevent rusting.

REMOVABLE SHUTTERS



F. Roofs

- the roof must be securely fixed to the rest of the structure. Failure to observe this rule is the greatest cause of damage to houses by hurricane force winds.

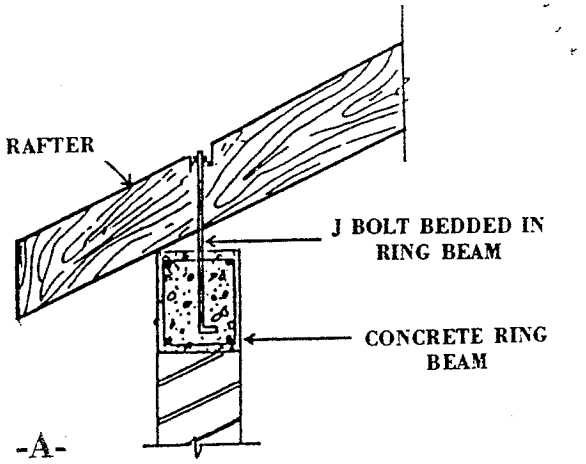
Fixing the roof to

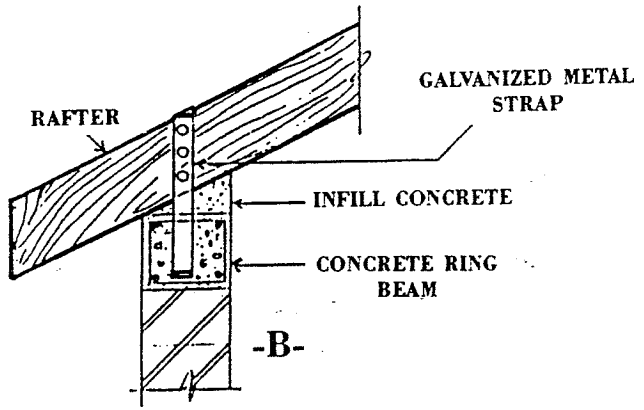
1. Concrete Blockwalls

a reinforced concrete ring beam 1 foot deep by the width of wall should be provided at roof level, to tie the walls together and to transfer the roof loads to walls. The following connections are recommended for fixing the roof members to the rest of the structure:

A. **J Bolts**
- 12mm diameter galvanize J bolts embedded in ring bean for at least 8 ins and threaded through pre-drilled holes in rafters will provide a secure connection. Not narrower than 3".

B. **Metal Strap in concrete**
- Hurricane straps made from 20 guage galvanized sheet metal, embedded in the concrete ring beam and nailed to the rafters. (Figure B).



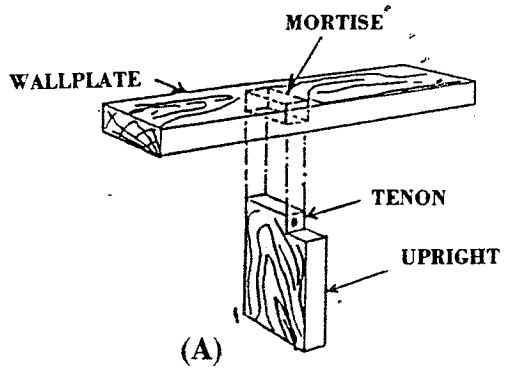


2. **Wooden Walls**

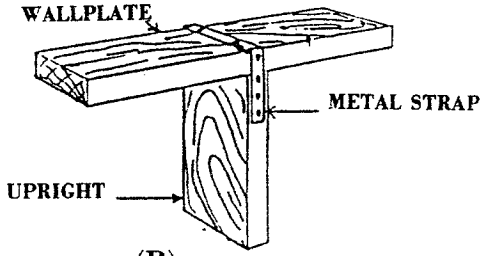
- In timber houses the rafters or trusses are connected to a wall plate which is supported by the vertical posts.

Two connections need to be considered.

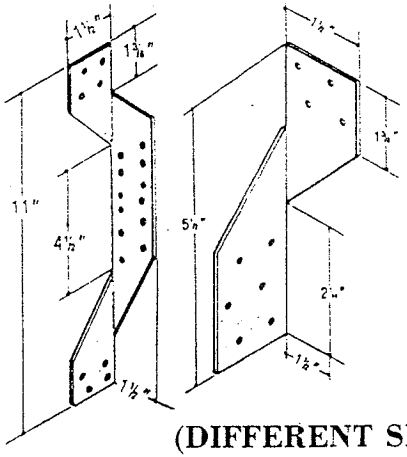
1. The first is the connection between the plate and the uprights which, as shown on Page 14, should be made using metal straps (Figure B). The conventional solution is a mortise and tenon joint (Figure A) using glue and sometimes dowel pins. Suction forces on the roof may cause this joint to fail.
2. The second connection is that between the rafter and the plate. The standard solution is to nail or spike the rafter to the wall plate. Under high suction forces these nails or spikes may pull out. It is strongly recommended that hurricane straps (or metal connectors) be used for these connections. The connectors may either be purchased off the shelf or made up on site using 20 guage galvanized sheet metal.

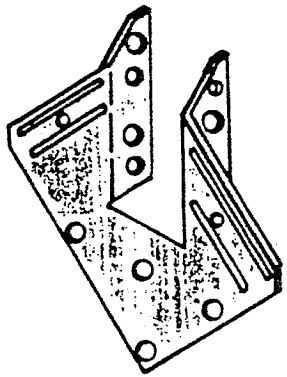


(A)

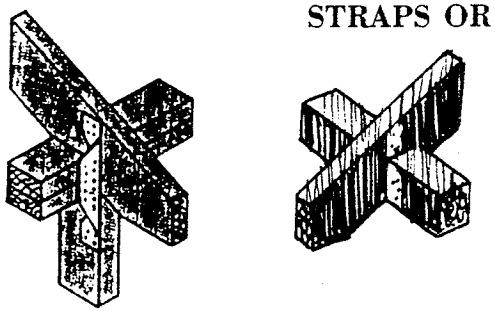


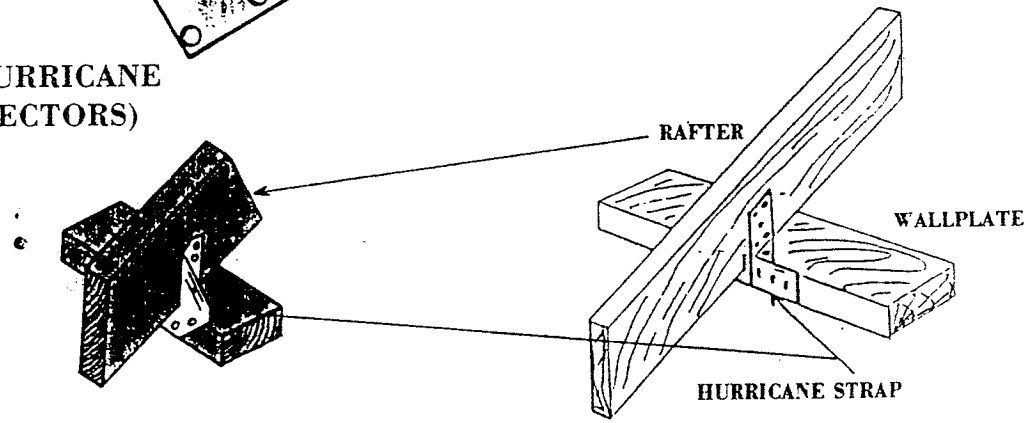
(B)





(DIFFERENT SHAPES OF HURRICANE STRAPS OR METAL CONNECTORS)





Roof Structure

The slope of the roof will affect how well it stands up to high winds. The best slope is in the 30° to 45° range, see Page 7. A slope of 1 in 2 is the absolute minimum that the roof should be. This means for every two feet of span horizontally the roof rises 1 foot vertically.

Gable Roof

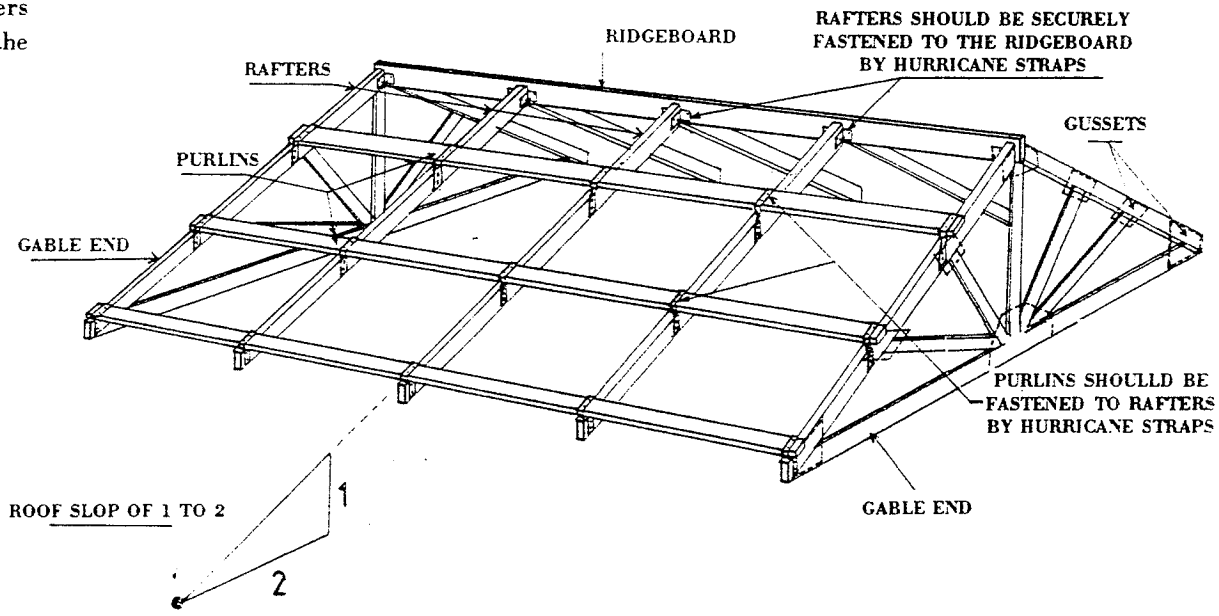
* This type of roof has two sloping sides. There are gable ends which are triangular (three cornered) sections that extend up to the ridge at both ends of the house. (Gussets) are flat pieces of wood, nailed to joints to strengthen them. Once gable ends are in place the ridge board should then be put on. This is the board at the centre of the roof to which the upper ends of rafters are attached. The ridgeboard must be firmly connected to the gable ends, using fasteners and straps.

* The following are recommended pitch pine rafter sizes for members 2' 0" apart for the given roof spans.

RAFTER SIZE	MAX. ROOF WIDTH
2" x 4"	16' - 0"
3" x 4"	20' - 0"
2" x 6"	25' - 0"
3" x 6"	30' - 0"

- once rafters are in position, gable ends and ridgeboard are in firmly, purlins should be fastened to the rafters by metal straps.

* In terms of hurricane resistance, the connections should have metal straps where the rafter and vertical post meet at the plate. The galvanized metal strap is nailed to the post and plate and then to the rafter. Metal straps may be made by the builder from 20 guage galvanized sheet metal.



GABLE ROOF
ROOF STRUCTURE & CONNECTIONS

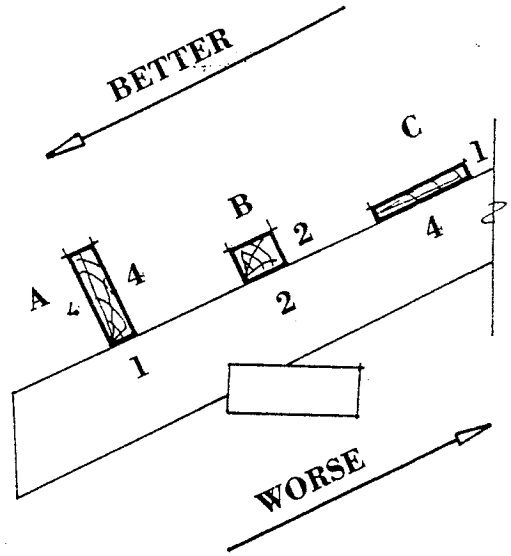
* ORIENTATION OF LATHES AND PURLINE

- The correct orientation of purlins on rafters is to put the deep side of the purlin perpendicular to the rafter. This maximises the strength of the purlin and minimises its deflection.

- The schedule below shows the relationship between strength and deflection for three situations where the same cross sectional area of material is used.

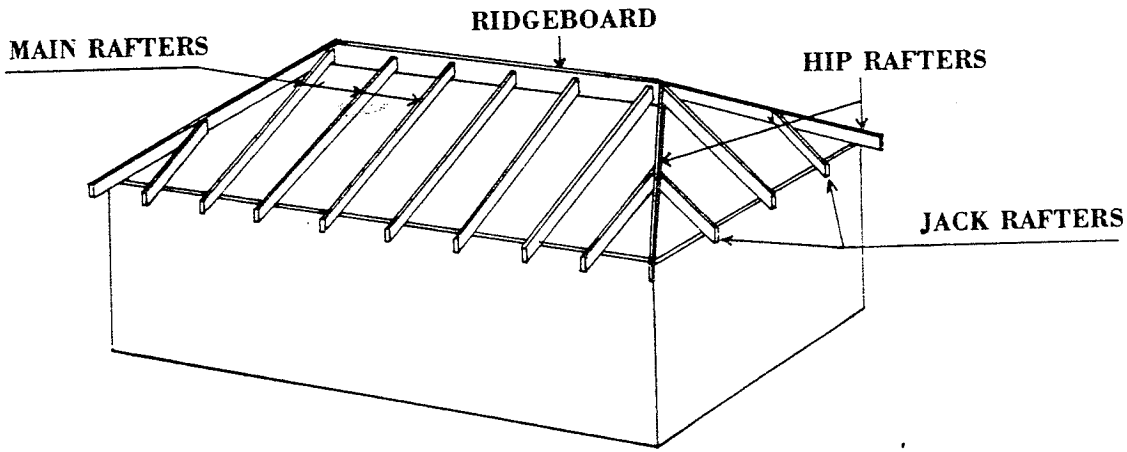
POSITION	A	B	C
Deflection	1	4	16
Strength	4	2	1

- Spacing between purlins should not exceed 2' - 0".

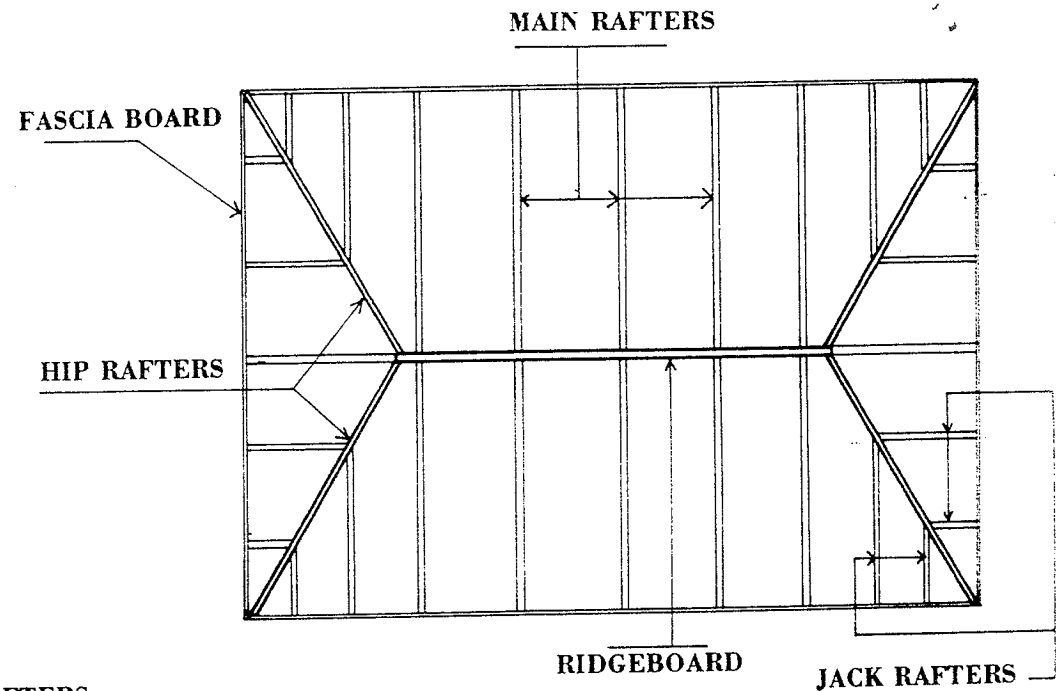


* Hipped Roof

This is the strongest type with all sides of the roof sloped. There are no gable ends in this roof. Instead, rafters come across diagonally from the corner and meet the ridge board a short distance in from the ends of the house. These are the hip rafters. Other shorter rafters go from the wall plate to the hip rafter and are called jack rafters.
After the ridge is firmly in position, the rafters are attached to fit neatly onto the wall plate.



HIPPED ROOF



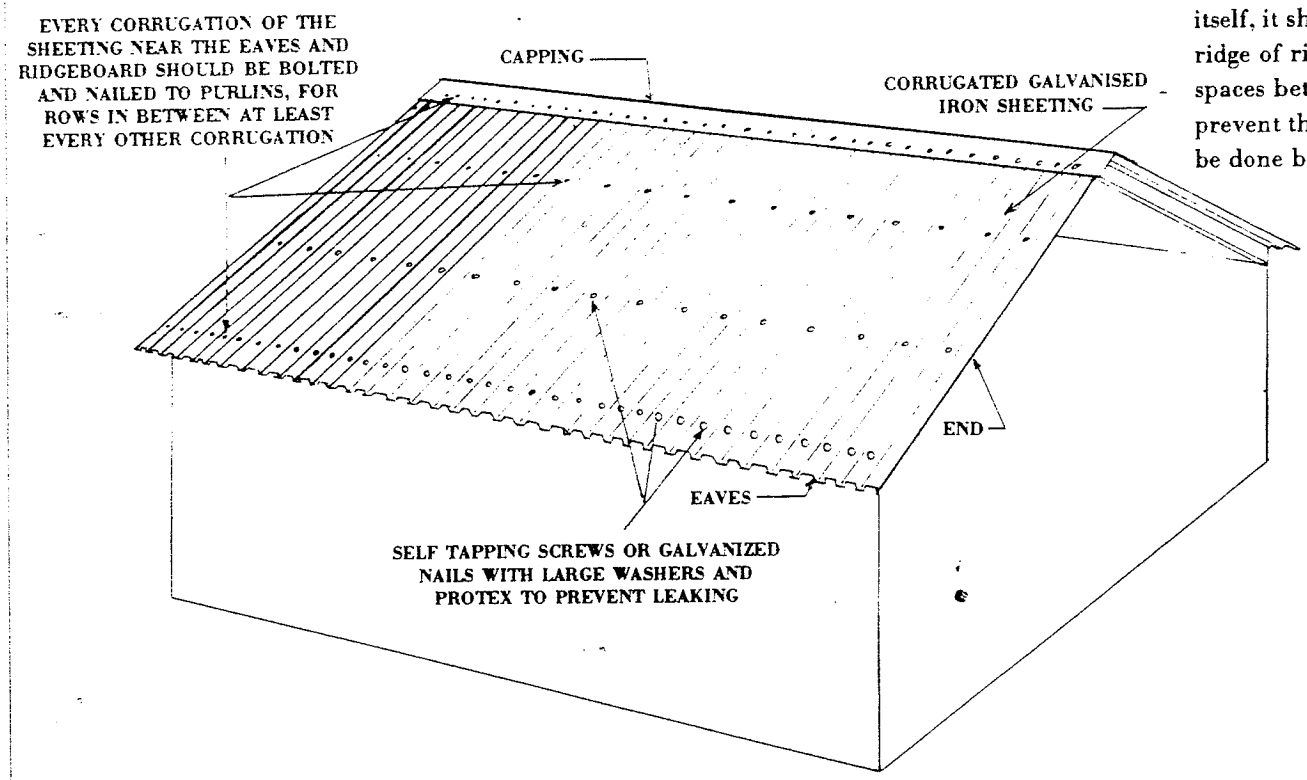
PLAN HIPPED ROOF

4. ROOF CLADDING

In addition to the roof structure being fixed to the supporting wall, the cladding must be able to resist and transfer the wind loads to the purlins. Purlins are therefore important structural members of the roof and flat boards should not be used for this purpose. Purlins should be either 2" x 2" or 1" x 4" at no more than 2' 0" spacing. Purlins should be fixed to each rafter passed over using hurricane straps or metal cleats.

* Corrugated galvanized steel sheeting is the most commonly used form of cladding in the Eastern Caribbean. Sheeting which is too thin and with inadequate numbers of fixings is extremely vulnerable during hurricanes. The minumum thickness of corrugated steel sheeting should be 0·6 mm.
- sheets should be fixed to the purlins using self-tapping screws or galvanized nails with large washer.
- at the eaves and ridge as well as the gable ends, the fixings should be two corrugations apart, and for the rest of the roof, no more than three corrugations apart.
- the corrugated sheeting should be properly overlapped (at least 2 1/2 corrugation) to prevent water from blowing under the seam.
- roof capping should be made from materials as strong as the sheeting itself, it should be bolted or screwed down to the purlin on either side of ridge of ridgeboard or hip.
- 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.

CONNECTION OF SHEETING & CAPPING

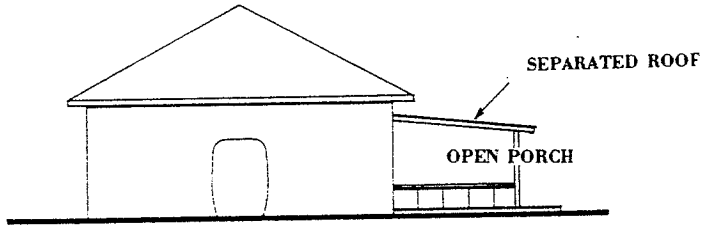


- Close boarding

Is another popular form of roof cladding. It is used with asphalt tiles. The close boarding is nailed directly onto the rafters and offers very good resistance to wind forces.

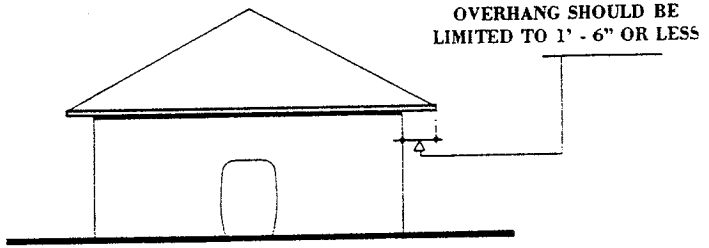
- Open Porches

Wind trapped underneath an open or half porch will impose high uplift forces on the roof which may be sufficient to prise the cladding off the purlins. Half porches should be avoided. If this is not possible, a strengthened ceiling should be provided. The roof of a full porch should be separated from the rest of the house so that during a hurricane failure of the exposed porch roof will not endanger the rest of the structure.



Overhangs

Overhanging portions of the roof are also vulnerable to air trapped on the underside and should be limited to 1' 6" or less to reduce the danger to the main roof.



Concrete Slabs

Concrete roofs offer the best protection in hurricanes.

5. MATERIAL SELECTION AND USE:

A secure house depends, to a great extent, on the use of good quality materials, and the manner in which they are assembled.

Concrete Mixes

There are two main concrete mixes: 1:2:4 and 1:3:6

- The 1:2:4 mix has 1 part cement to 2 parts sand to 4 parts gravel (coarse aggregate).
- The 1:3:6 mix has 1 part cement to 3 parts sand to 6 parts gravel (coarse aggregate).
- Sand and gravel (coarse aggregate) should be clean and free from dirt.
- Use the right amount of water when mixing to get a good consistency.
- For every bag of cement use 5 gallons of water.
- Overwatering the mix will produce weaker concrete.
- If sand or gravel is wet before mixing starts, use less water.
- The 1:2:4 mix should be used for foundations, columns, beams lintels and slabs.
- The 1:3:6 mix may be used for filling concrete block pockets.

Mortar Mix

The 1:3 mix (1 part cement to 3 parts sand) should be used for mortar.

Reinforcing Steel

Reinforcing steel is used for strengthening concrete and blockwork.

All reinforcing steel should be high tensile steel (yield stress of 60 000 psi or more), but mild steel may be used for links with reduced spacing.

- Use 12mm diameter bars for:
  - foundations
  - main reinforcement in beams, columns, lintels, stiffeners, vertical bars in blockwork
  - vertical bars in blockwork.

- Use 8mm diameter bars for:
  - link in columns, beams, lintels and stiffeners

- Use galvanized Dur-O-Wal or Brickforce for horizontal reinforcement in blockwalls.

Wood

- All wood should be treated for termites. Wood in contact with the ground should be protected against rot; tar may be used for this purpose.

- Special attention should be given to sawn ends of wood.

- For various parts of the house, the following wood sizes are recommended:

  - wall sills 4" x 4" or 2" x 4"
  - wall plates 2" x 4"
  - Joists, posts, rafters 2" x 4" or 2" x 6", but see schedule on Page 13 and Page 21.
  - Purlins 1" x 4" or 2" x 2"

Straps, Bolts, Washers

- Hurricane straps may be made on site from 20 guage galvanized sheet metal.

- Galvanized bolts and washers should be used.

6. MAINTENANCE:

1. Experience and statistics show that the lack of maintenance is a significant contributing factor in damage to houses by hurricanes.

2. Regular maintenance is necessary in order to ensure that a structure continues to be hurricane resistant.

3. Check the entire house regularly inside and outside - to see if anything needs repairing or replacing, and fix it immediately.

4. The most important areas for regular checks are:

   a. Roof cladding for damge and fixings for missing screws or bolts.

   b. Roof structure; rafters and purlins for soundness.

   c. Joints and connections in timber and masonry construction for structural integrity and durability.

   d. Concrete blocks and slabs for cracks.

   e. For houses on wooden supports, check supports for rot, especially those below ground level.

   f. Check for termites and treat when evident. Obtain specialist advise for this problem.