INTRODUCTION TO
WIND RESISTANT HOUSING CONSTRUCTION

A GUIDE FOR AGENCIES IN THE CARIBBEAN

INTERTECT

INTRODUCTION TO WIND RESISTANT HOUSING CONSTRUCTION: A GUIDE FOR AGENCIES IN THE CARIBBEAN

This booklet is designed to provide an introduction to the basics of wind resistant housing construction. It has been developed for the use of relief agency personnel who may become involved in planning housing programs in developing countries, especially in regions where hurricanes, cyclones or typhoons are prevalent.

The objective of the booklet is to provide non-technical personnel with the necessary background information upon which to base decisions relating to the formulation of plans for housing programs. The material set forth herein pertains to the types of housing built by low income families, and it is hoped that the booklet will be useful for agencies planning self-help housing programs.

INTERTECT welcomes comments on the booklet and suggestions as to how it might be improved.

INTERTECT

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INTRODUCTION TO WIND RESISTANT HOUSING CONSTRUCTION: A GUIDE FOR AGENCIES IN THE CARIBBEAN

Introduction

In regions subject to severe wind storms, the question is often asked, "can the houses made by traditional building methods in the developing countries be made safe enough to withstand high, or even hurricane-strength, winds?". The answer is that any house, using any type of building material, can be made wind resistant as long as certain principles of design are understood and certain rules of construction are followed.

I. How High Winds Damage a House

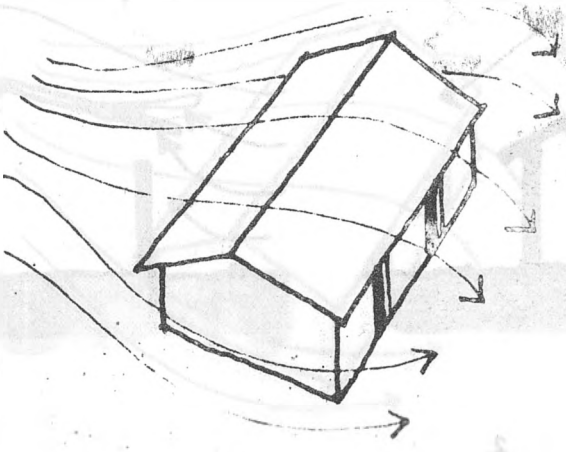
In order to understand how to build a house that can resist high winds, it is necessary first to understand how winds damage a structure.

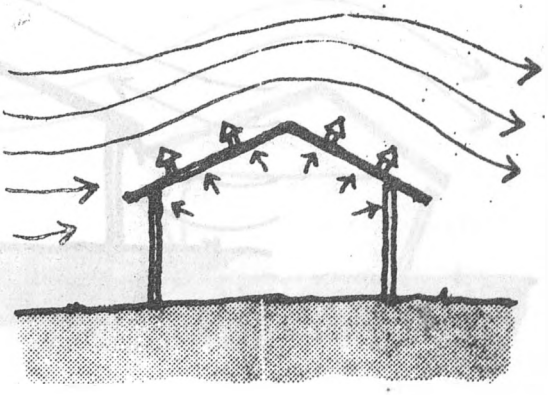
A. Wind Effects on a House.

Winds destroy houses in two ways: roof uplift and strong forces on the walls.

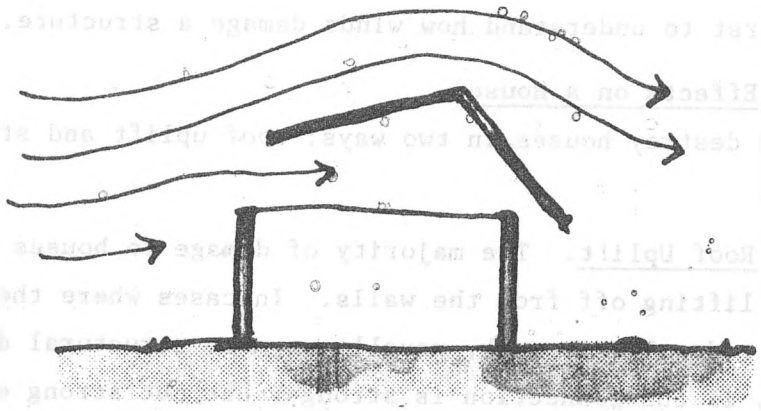
1. Roof Uplift. The majority of damage to houses is caused by the roof lifting off from the walls. In cases where the connection between roof and walls is weak, usually no more structural damage occurs. However, if the connection is stronger but not strong enough to keep the roof on, then some damage will occur as the roof separates from the walls.

The forces which cause the roof to fly off the top of the walls may be a result of one or all of the three following factors. First is the lift caused by wind moving rapidly over the top surface of the roof. This lift is created when the wind strikes the windward side of the house and is forced to separate in order to reach the other side of the building.

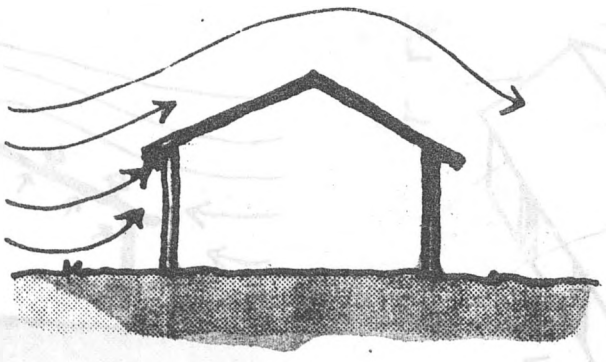


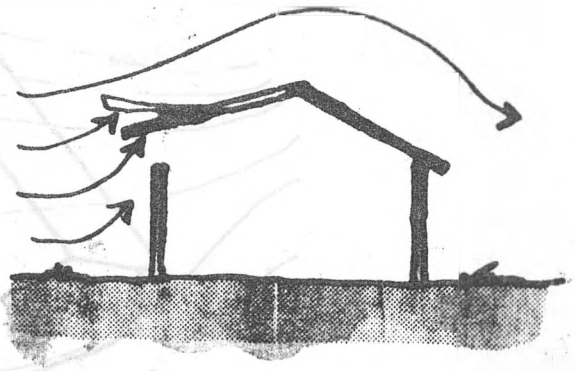


The portion of the wind that moves over the roof must travel at a faster speed than the wind moving around the structure in order to reach the other side at the same time. The faster the air moves over the top of the surface, the less pressure is created on that surface; thus suction begins to form which pulls the roof upward. If the inside of the house remains relatively airtight and no moving air enters the house, the pressure inside the structure will remain constant. However, in relation to the pressure outside, this inside pressure is considered positive, while the air flowing over the outside of the structure is a negative pressure. The positive pressure pushes outward on the roof and the walls at the same time that negative pressure is pulling outward. If the roof is not securely fastened to the walls, it will blow off.

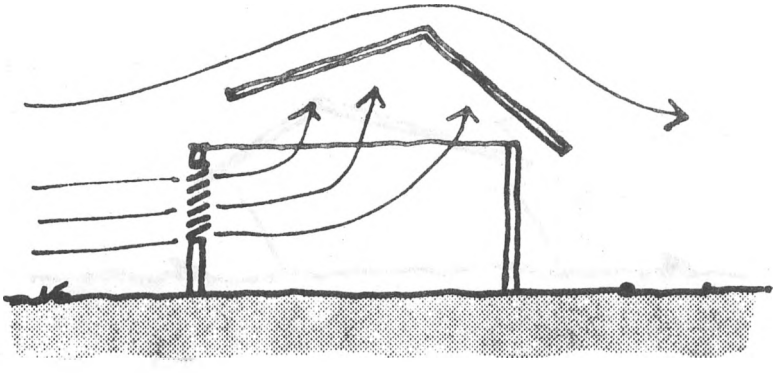


The second factor is the wind pushing up on the edges of the roof. As the wind strikes the windward side of a wall, a portion of the wind is deflected upward. If the eave of the house extends too far from the wall, or if the eave is designed to act as a trap for the wind, a tremendous amount of pressure can be placed on the edge of the roof and this pressure can pry the roof (or portions of the roof) away from the wall.



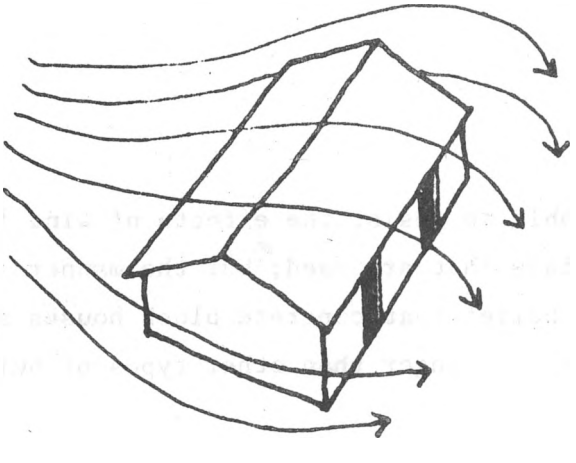


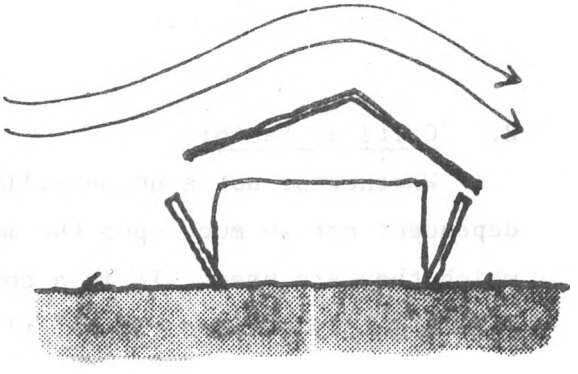
The third factor is the wind pushing upward on the roof from the inside of the house. If doors, windows and ventilators are not securely battened down, wind can enter the house with tremendous force and push upward from the inside. This force may add to the forces already created by positive pressure within the structure, or may add to the forces pushing upward on the edges of the roof under the eaves, and the combination may be enough to lift the roof away from the walls.



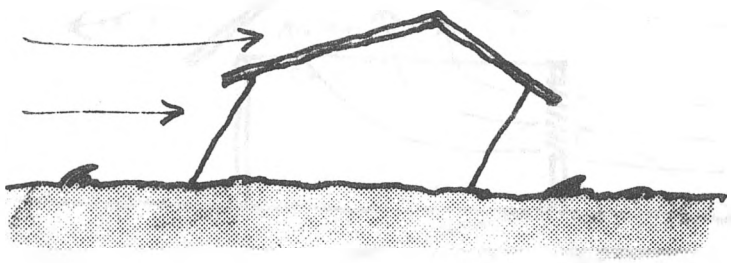
2. Forces on the Walls. The forces created by winds blowing against the walls can also cause structural failure in a house. There are three ways in which the forces on the walls create failure.

First is the outward explosion of the house caused by differential pressure. As noted earlier, the winds rushing around the structure create an outward pulling suction, while the constant pressure on the inside of the house creates positive pressure which, in turn, pushes outward from the inside. The faster the winds blow, the greater the pressure differential; and if the walls are not built strongly, nor properly reinforced or tied together, eventually this outward pressure will be too great and the house will simply explode.

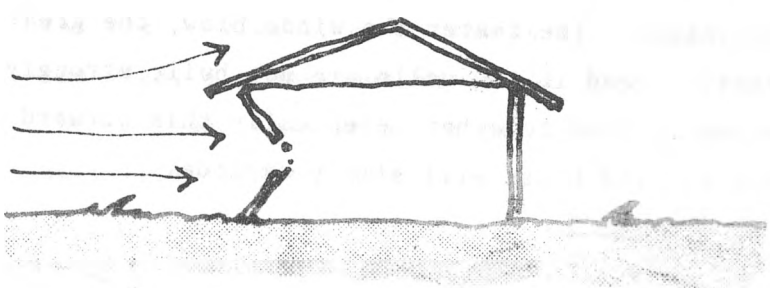




The second cause is horizontal displacement. Displacement occurs when the forces created by the winds pushing on the windward side and pulling from the leeward side cause the building to move relative to its position on its foundation. Normally, this type of damage is characterized by the building tending to collapse from the roofline downward and to distort into the shape illustrated below. This type of damage is most often seen in wooden housing but can occur in any type of building.



The third is failure of the wall on the windward side due to the extreme forces of the wind. If the walls of the building are not properly reinforced, the heavy load caused by wind gusts on the wall can cause the wall to collapse. This is often the case in block or rock structures that are not properly reinforced with ring beams and columns.



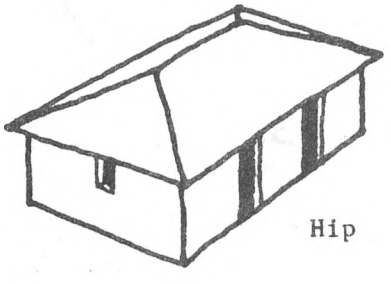
B. Critical Factors

Whether or not a house 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 concrete block houses are safer, simply because the materials are stronger than other types of building

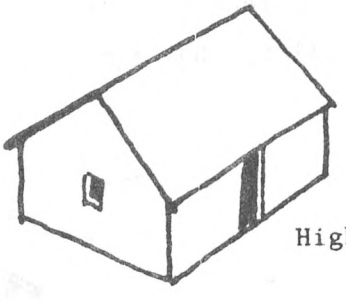
materials. While it is true that a well-built and properly-engineered block house offers a better margin of safety than other types of buildings, safe housing can be and has been made from a variety of other materials including wood, wattle-and-daub, and many others. In some parts of Asia, houses made of bamboo with palm leaf roofs have withstood typhoons for hundreds of years with relatively minor damage.

What, then, are the critical factors which determine the safety of a house? They are:

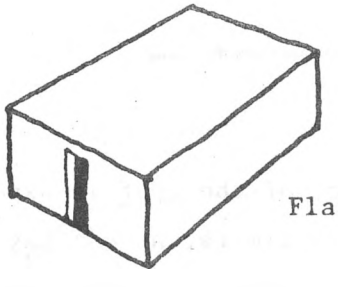
1. Configuration of the Roof. Recent studies of different roof designs have shown that houses with hip roofs (that is, four-sided or pyramid-shaped roofs) have the best record of resistance. This is because it is difficult for equal pressure to develop across an entire roof surface. In descending order of safety, the roof configurations are: hip roof; gabled roof (with 30^{o}-45^{o} pitch); flat roof; gabled roof (with less than 25^{o} pitch).



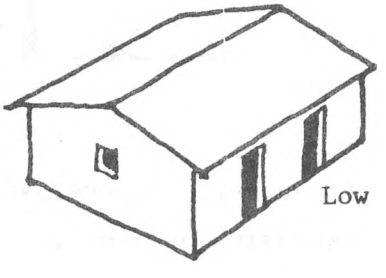
Hip



High Gabled



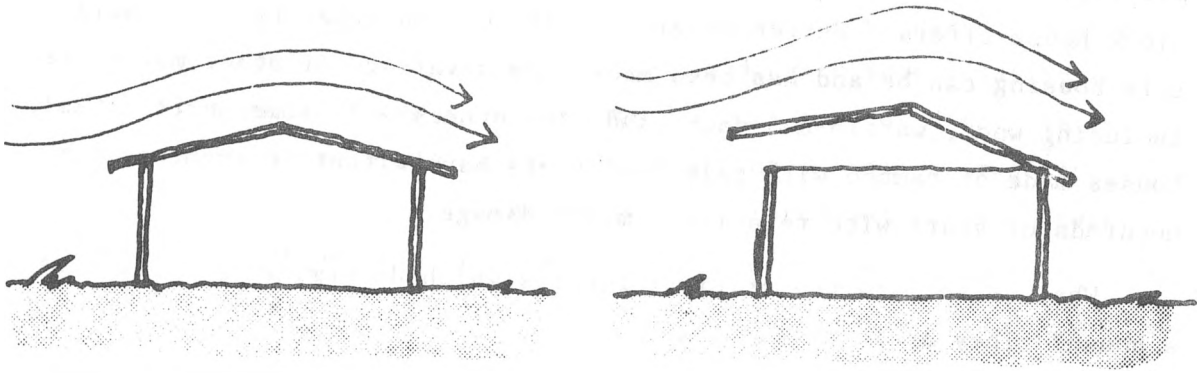
Flat



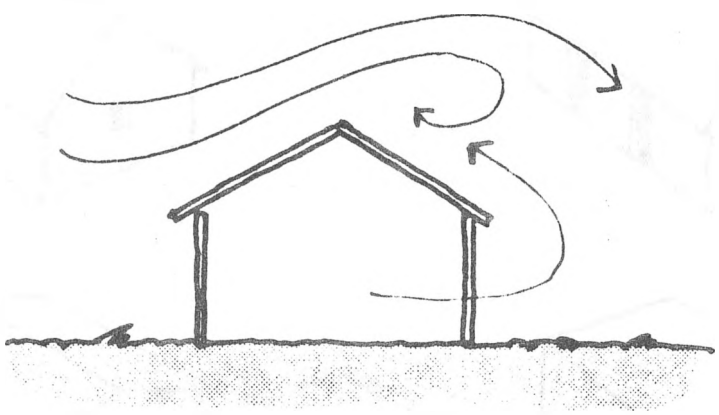
Low Gabled

2. The Pitch or Angle of the Roof. The safest angle for the roof pitch is between 30^{o} and 45^{o}. If a roof has less than 30^{o} of pitch, the air moving over the surface can reach the trailing edge (or leeward side of the roof) undisturbed and at the same time that the air moving around the structure reaches the same point. Thus, the conditions necessary to create lift on the roof can be met and the

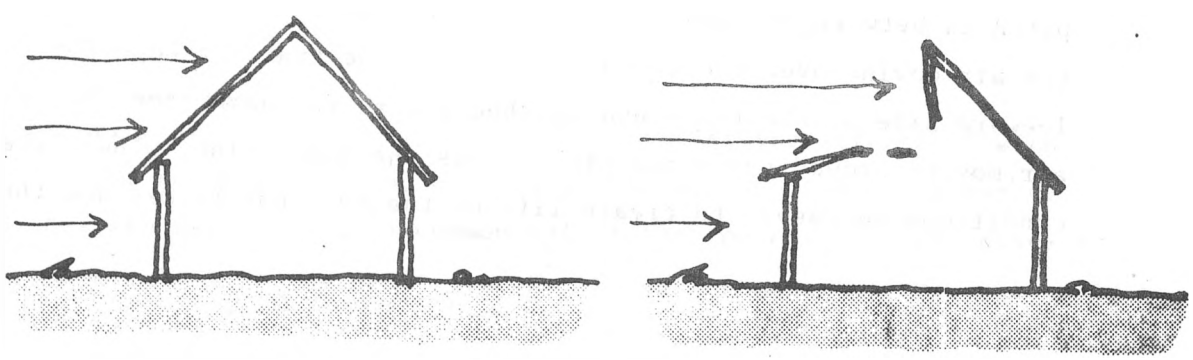
roof will blow off.



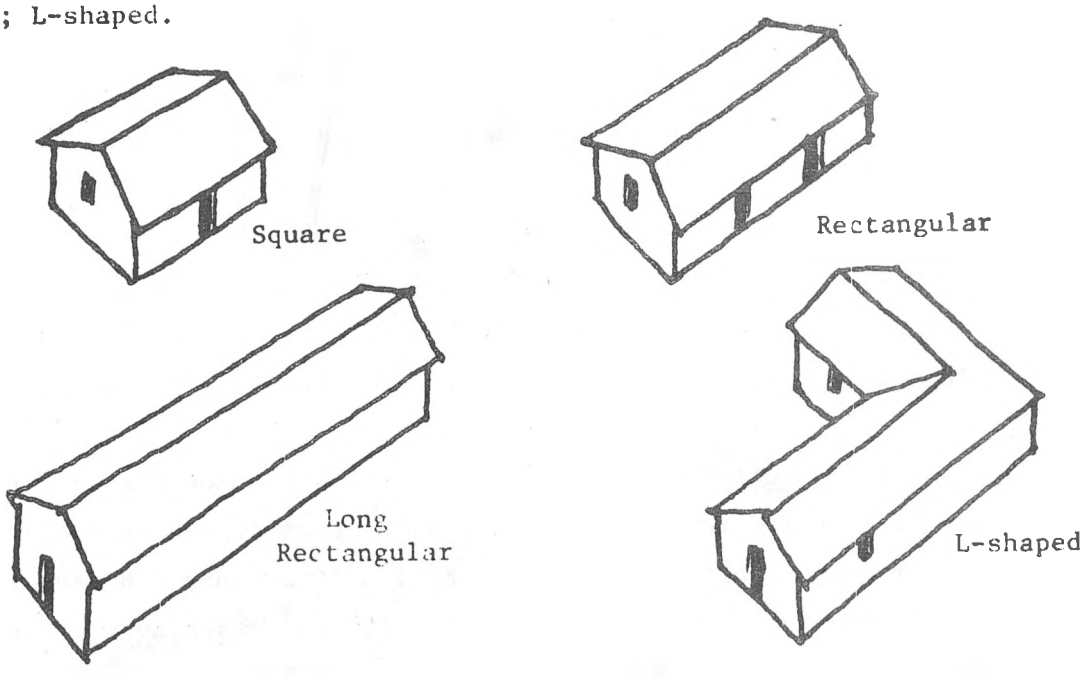
At an angle between 30^{o} and 45^{o}, it is not possible for the wind to reach the trailing edge at the same time that the wind coming around the sides of the house hits that point. Therefore, a portion of the air must rush back across the surface in the opposite direction to meet the air coming over the top. This creates turbulence on top of the roof but breaks up the uplifting suction and reduces the possibility that the roof will lift off.



At an angle of over 45^{o}, the windward face of the roof is exposed to excessive pressure. While, within certain limits, a roof may be able to withstand this pressure, it requires extensive reinforcement of the roof surface and a much more costly roof frame and truss support system.

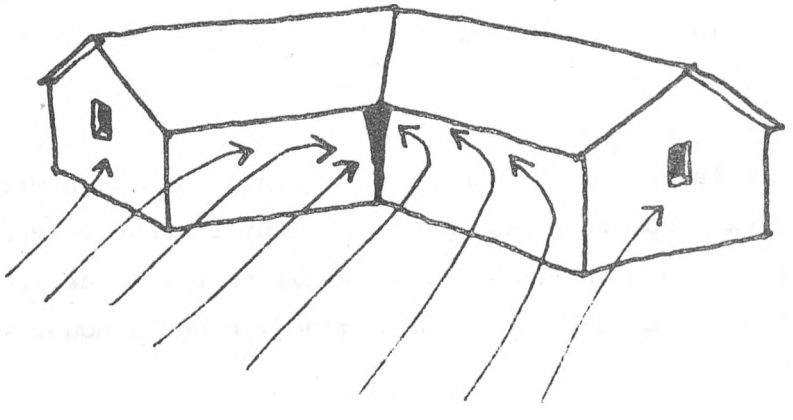


3. Configuration or Plan of the House. Studies have shown that the most efficient forms for the plan of a house to withstand high winds are (in descending order of safety): square; rectangular; long rectangular; L-shaped.



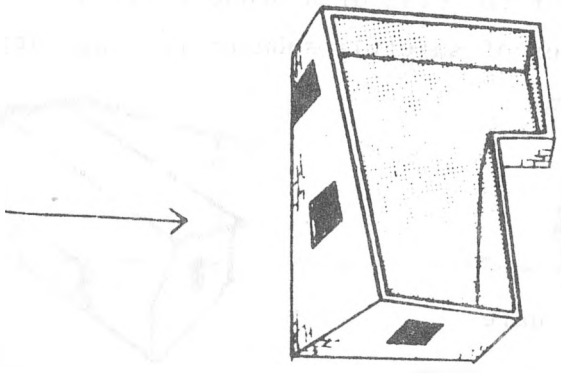
As most houses are built in a rectangular fashion, it is helpful to know that the best length-to-width ratio is 3:1 or less. In other words, in an area where high winds might occur, it is best not to design a house that is more than 3 times longer than it is wide.

The case of the L-shaped house is one of particular interest. Not only is this housing type especially vulnerable to winds due to the way the "L" shape channels the winds into the juncture between the two wings, causing collapse there:



but also because winds striking the house from the other sides can

create a racking effect on the house which tends to cause the structure to collapse inward.



This form of house, therefore, should especially be avoided.

4. Siting of a House. The location where a house is built, as well as its relation to other structures or land forms, can play an important part in the survivability of a house. Houses that are built on stilts on hillsides, close to the coastline where strong winds sweeping in from the sea could be deflected upward, stand a good chance of being blown off their foundations. Likewise, houses situated in long, narrow valleys which open onto the sea may be knocked down by the "funnel effect" created by the winds forced into the confines of the valley. Houses built in long, straight lines, close together in a grid layout (as is often popular in government housing schemes), can also be subject to "funnel effect" during hurricanes. Staggering the houses, and taking advantage of natural windbreaks (such as land forms, stands of trees, or through the imaginative siting of groups of buildings) can significantly reduce the forces from winds funnelled or deflected by land masses.

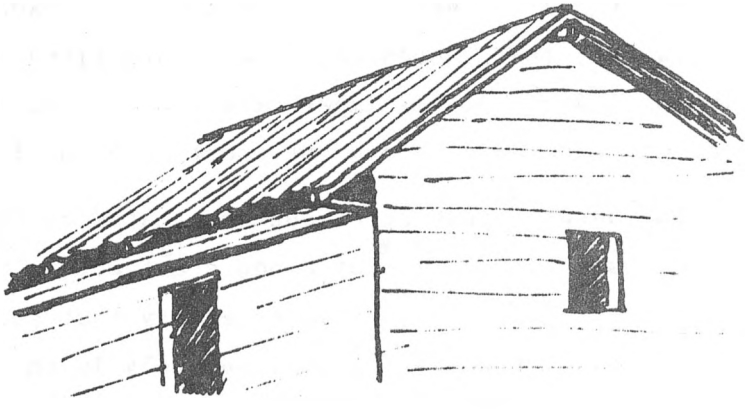
C. Critical Points of a House

When a house fails in a high wind, it is usually due to a weakness that can be traced to a particular point in the structure. Researchers have examined many different houses destroyed by winds to try to define the critical points of a house in order to determine whether a house will remain intact. These points are:

1. The Attachment of the Roof Material to the Roof Frame. Often,

roofing material is blown off the roof simply because it it not fastened securely. This is especially important when corrugated iron sheeting is used as the roof material. It has been shown that, by simply doubling the number of nails used to hold the sheets onto the roof, the likelihood of the sheets blowing off in high winds can be reduced substantially.

2. Roof Overhang. It has been shown that a roof overhang of less than 46 cm. (18"), and one that prevents the air from being trapped under the eave of the roof, will prevent the roof cover from peeling off and substantially reduce the upward forces acting on the edge of the roof.



3. Roof-Wall Connection. The roof-wall connection is probably the most critical factor in the survivability of a house. If the roof stays on the house and the walls are sufficiently strong, there is little likelihood of the house being destroyed and any damage will most likely be light. Therefore, it is of the utmost importance that sufficient attention be given to attaching the roof and the roof frame securely to the walls.

4. Wall Strength. In order for a wall to withstand high winds, it must be properly bonded and reinforced. In the case of wooden walls, this means that the wood siding must be securely nailed to the frame and that sufficient vertical columns must be used to help strengthen the wooden siding. In the case of concrete block walls, it means that both vertical columns and ring beams must be used, as well as a good mortar to cement and level the blocks themselves.

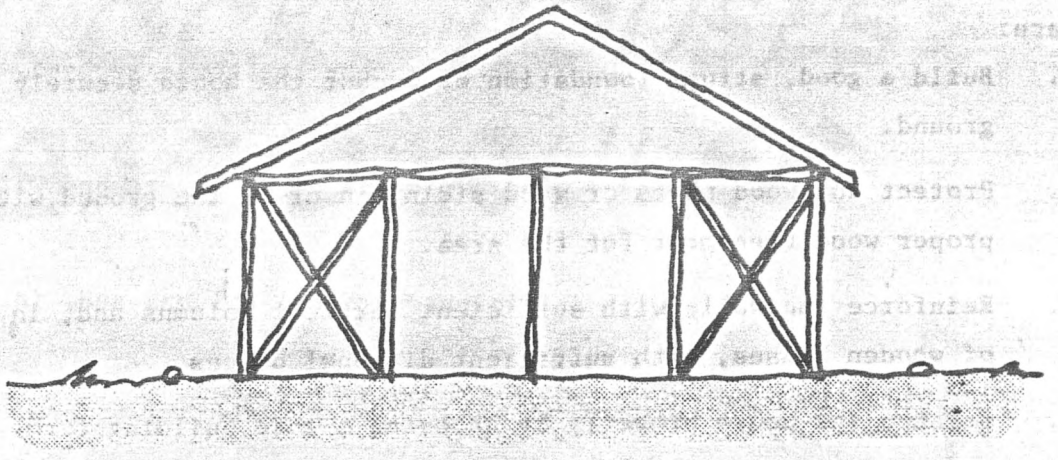
5. Windows. One of the major problems in hurricanes is the sudden opening of a window or door which allows the force of the wind to penetrate the interior of the house and begin pushing outward on the roof and walls. Louvered windows are particularly vulnerable; and glass windows, unless protected by shutters, are subject to breakage either by the force of the wind itself or by flying debris. It is imperative that all windows be shuttered or securely battened prior to a hurricane.

6. Air Vents at Doors and Windows. In the tropics, where circulation of air within a house is needed to keep interior temperatures at a pleasant level, air vents are often added above doors and windows. During hurricanes, these air vents allow the entry of excessive amounts of air, which often causes the same damage cited in the discussion of windows. Again, it is imperative that any air vents either be shuttered or battened down before the onset of a hurricane.

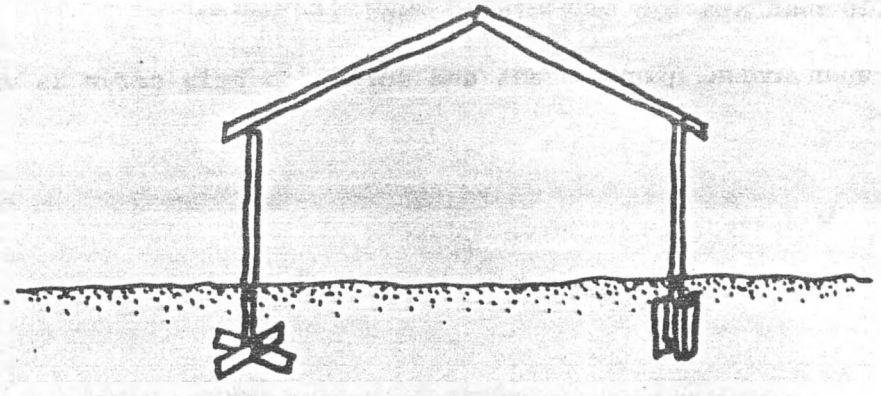
7. Corners. The outward-pushing pressures created by the differing pressure on the outside and inside of a house attempt to push the walls away from each other. Therefore, it is necessary that special attention be given to tying the walls together securely in the corners. This is especially important in wood buildings, and special attention should be given to reinforcing the corners at the top of the walls with a diagonal brace. This not only serves to hold the walls together at the top, but can also reduce the racking effect caused by disproportionate pressures on two adjoining sides of a house.

8. Bracing the Walls. In order to reduce the chance of the walls being pushed in from the top, and in order to reduce failure at the corners, houses made of wood, wattle-and-daub or slip-form concrete should have some form of diagonal bracing (preferably X-bracing) at the corners. This will give additional strength to walls on the windward side of the structure and will help hold the house together against the wind pressure from both inside and outside the structure. X-bracing is recommended as it adds a dual measure of strength and provides reinforcement for the corners as well as for the vertical columns in

the walls.



9. Anchoring of the House to the Ground. All houses must be securely anchored to the ground. In the case of wooden houses, or structures that use wooden vertical columns, these posts should not only be set deeply into the ground but should also have some form of anchoring device attached at the base. If soft woods are used, they must be treated first to resist insects and rot caused by moisture in the ground.



In the case of concrete block houses, a good strong foundation with a moisture barrier should be built, and the iron rods of the vertical columns should be securely anchored in the foundation.

II. How to Build a Safe House

There are 9 basic rules to remember in order to build a safer house. These are:

A. Build a good, strong foundation or anchor the house securely to the ground.

B. Protect any wood posts or wood siding in or on the ground with the proper wood treatment for the area.

C. Reinforce the walls with sufficient vertical columns and, in the case of wooden houses, with sufficient diagonal braces.

D. Balance the house properly by choosing a safe building form.

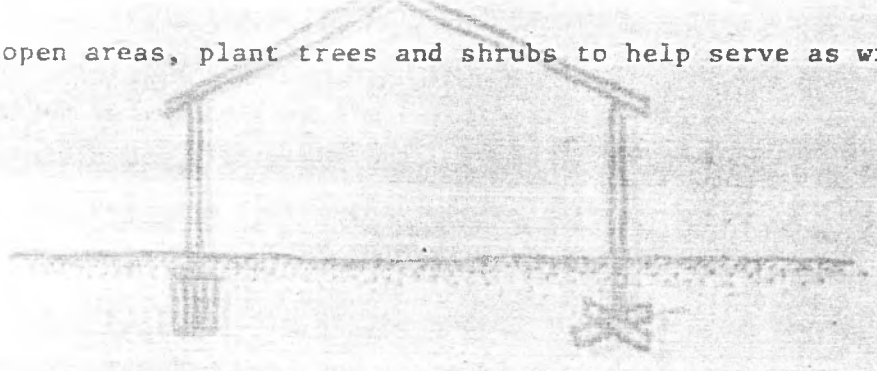
E. Build a good connection between walls and roof. Add extra strength to this connection by using metal straps or other methods to attach the roof to the walls.

F. Use a hip roof (4-agua) with a roof pitch angle of 30°-45°.

G. Do not extend the eave of a roof more than 46 cm. (18") from the wall; and cover the underside of the eave with wood.

H. Build shutters for all windows and air vents.

I. In open areas, plant trees and shrubs to help serve as windbreaks.



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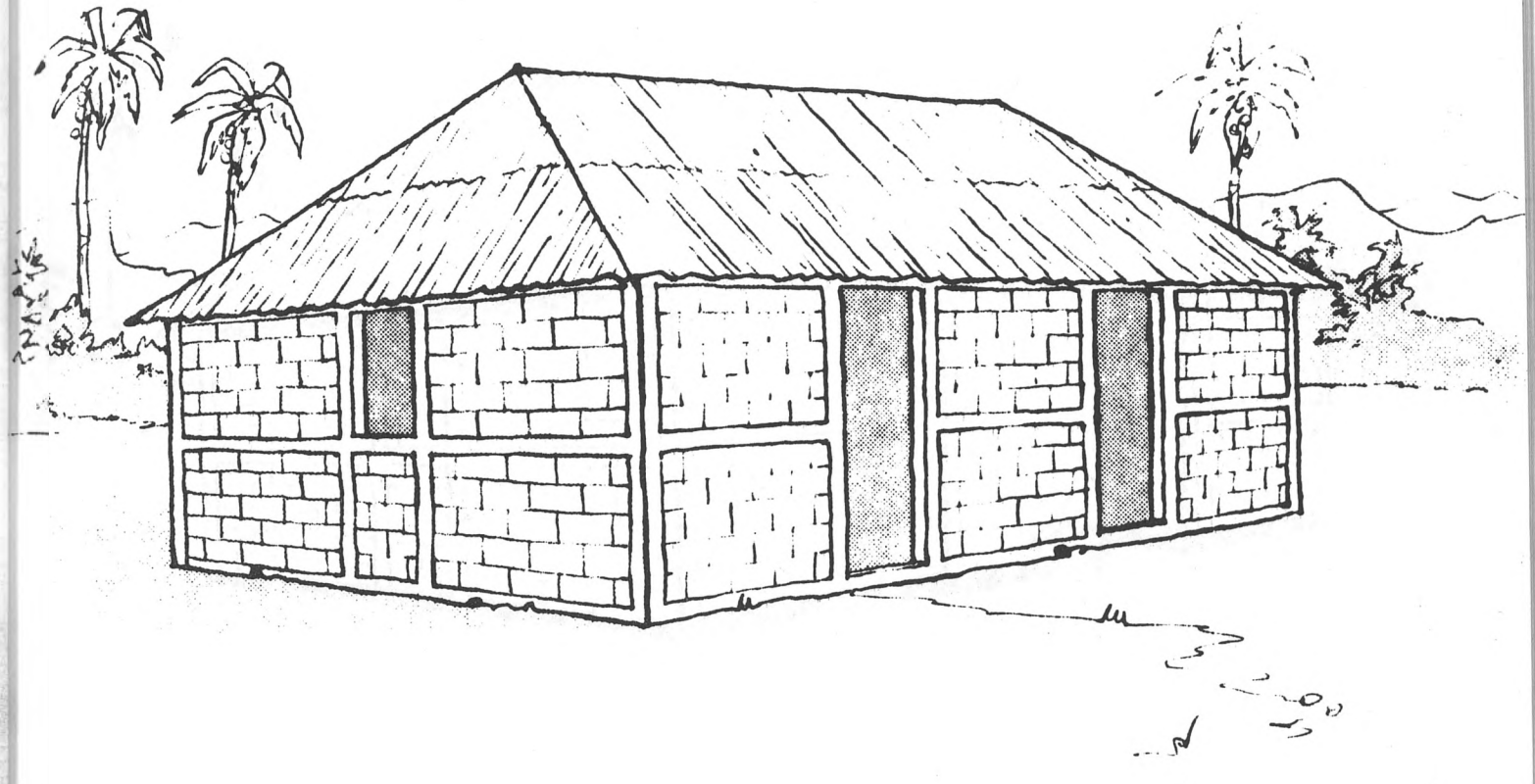
WIND RESISTANT BLOCK HOUSES: BASIC RULES



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WIND RESISTANT BLOCK HOUSES: BASIC RULES

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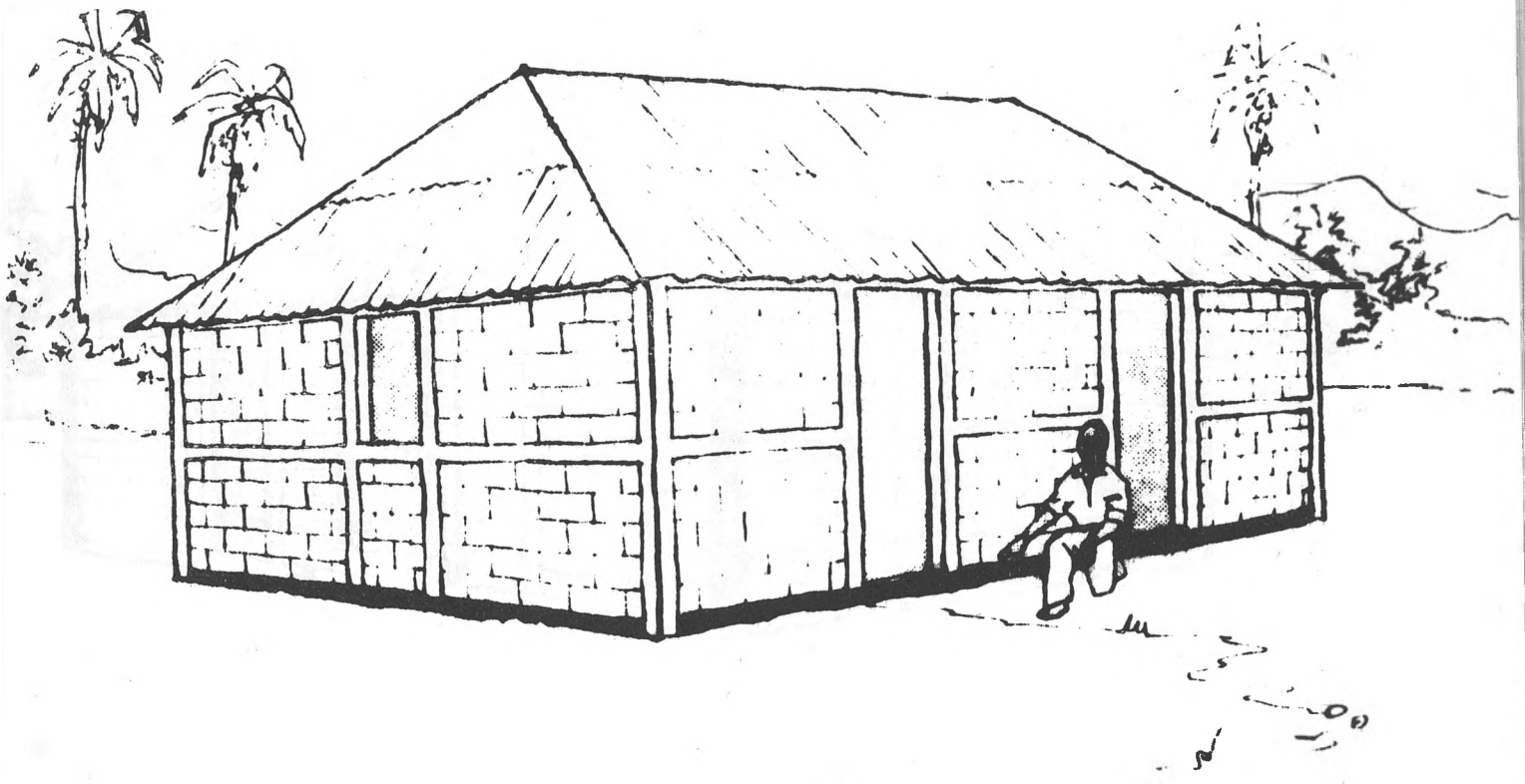
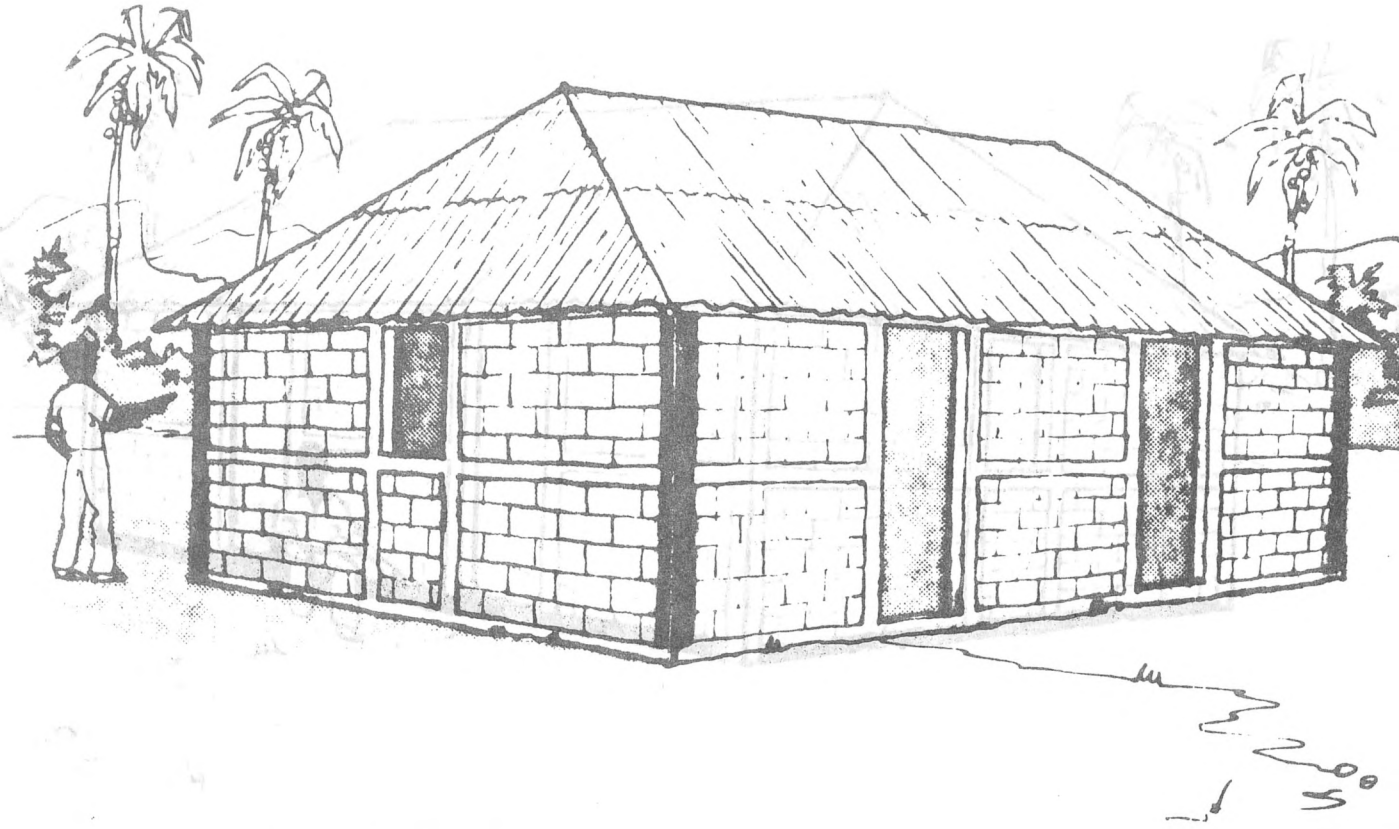
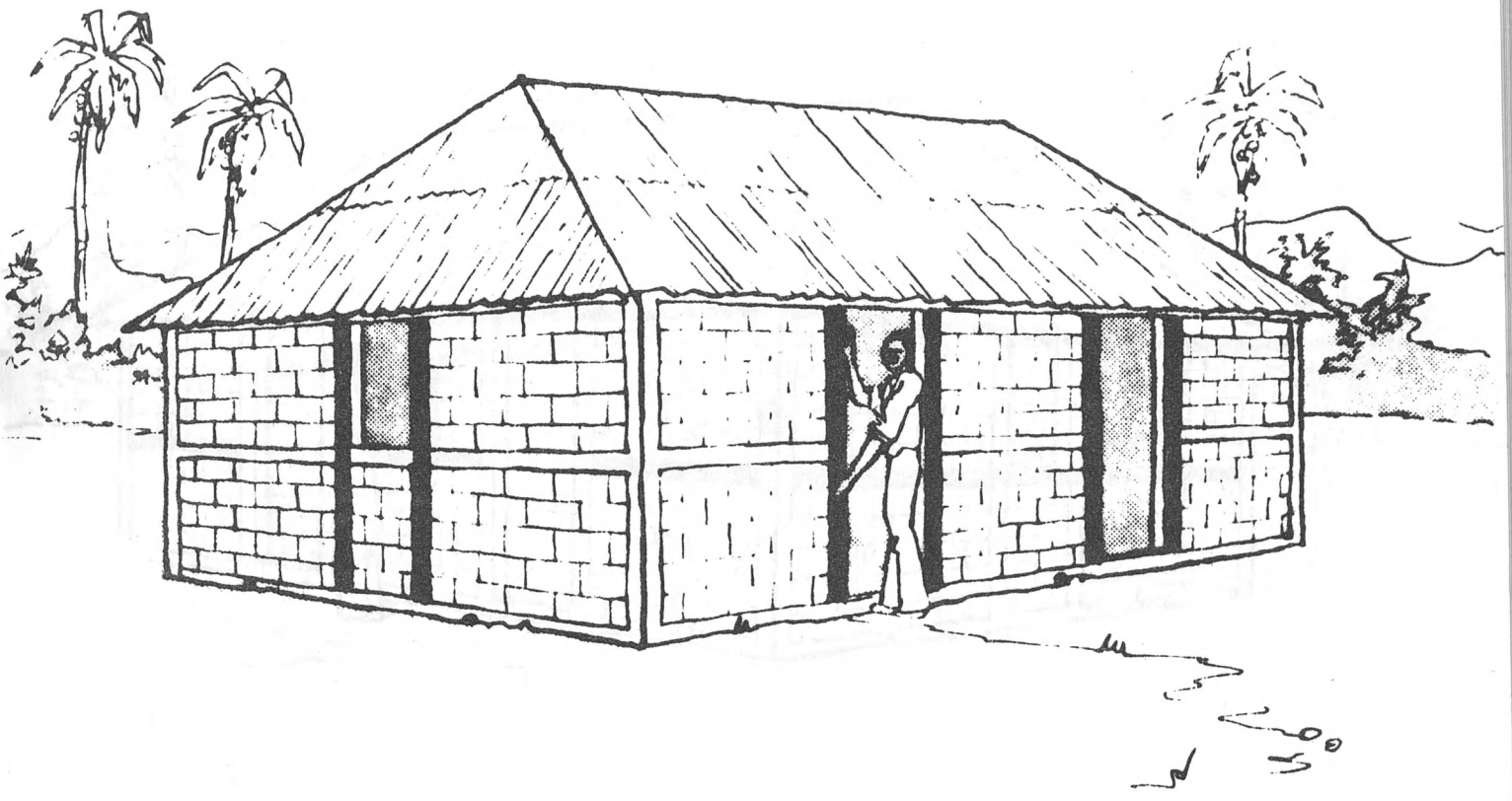


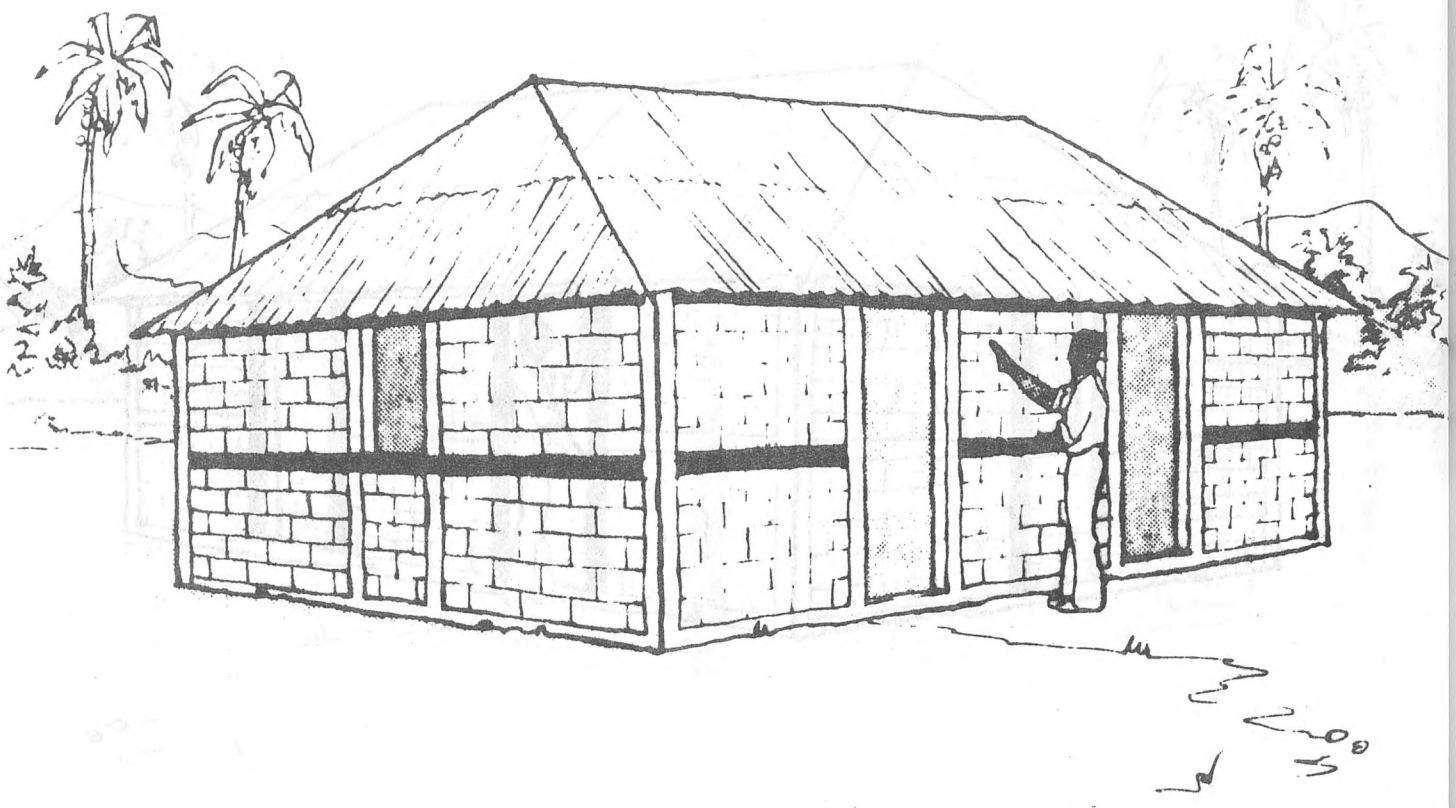
Build a strong foundation reinforced with iron rods, and build it a minimum of 12 inches above the ground to serve as a moisture barrier.



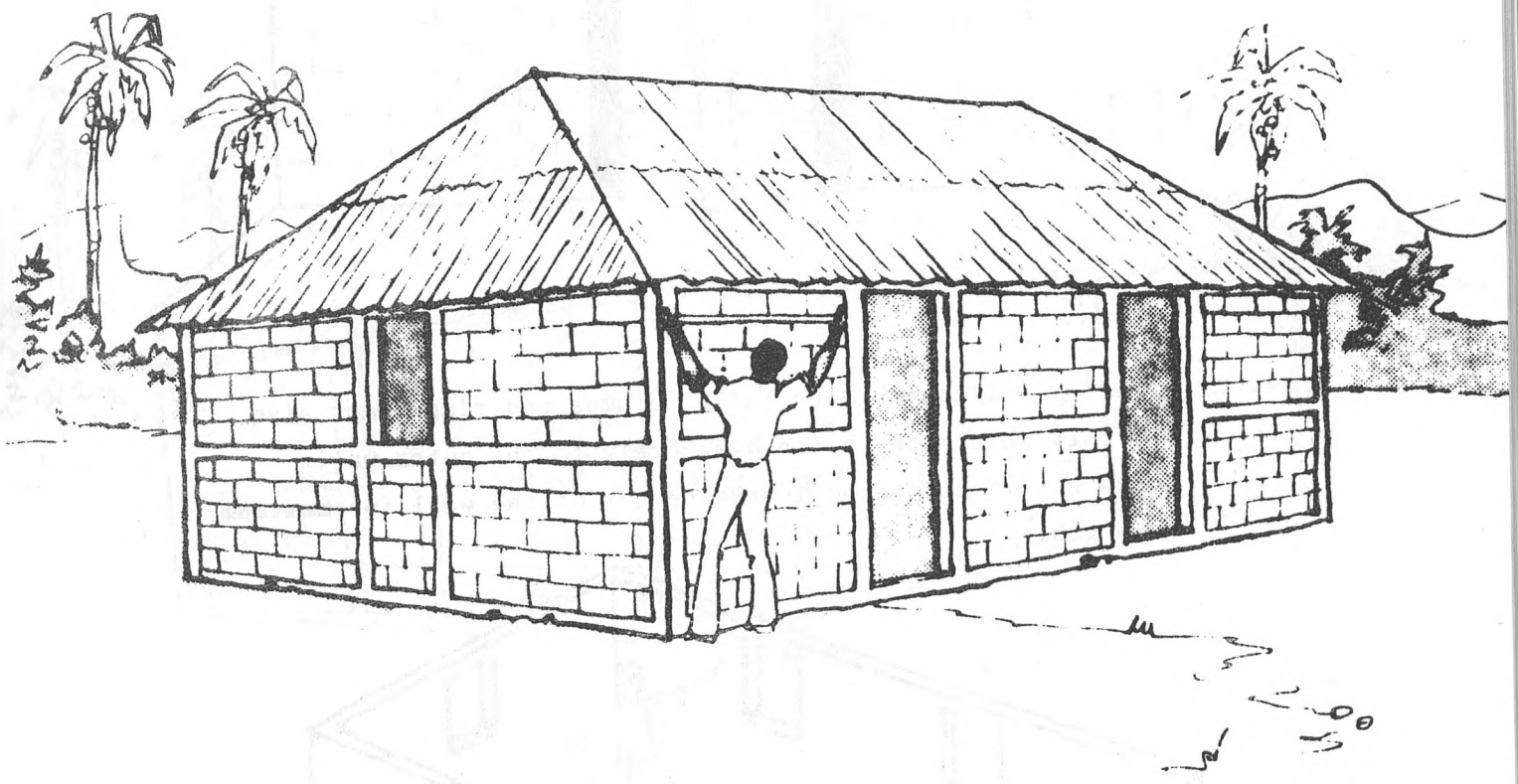
Place cement colomns reinforced with iron rods in each corner.



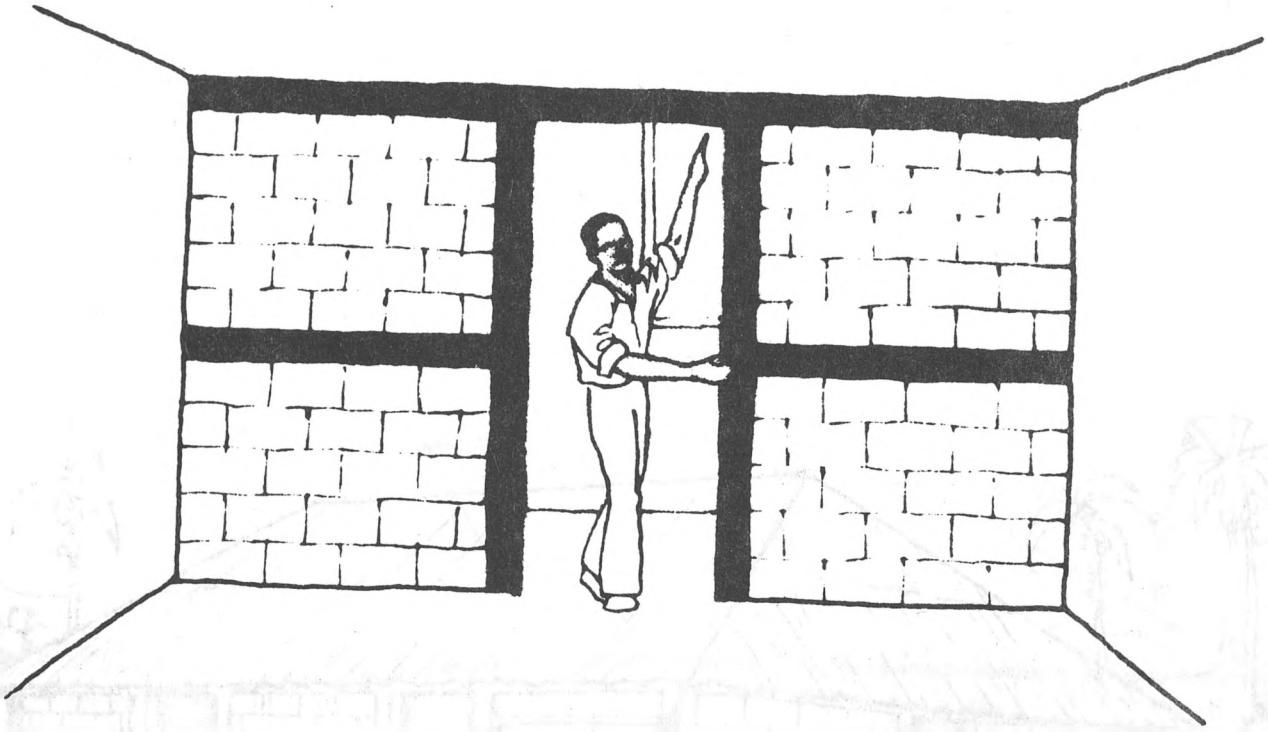
Place reinforced columns at the side of each door and window.



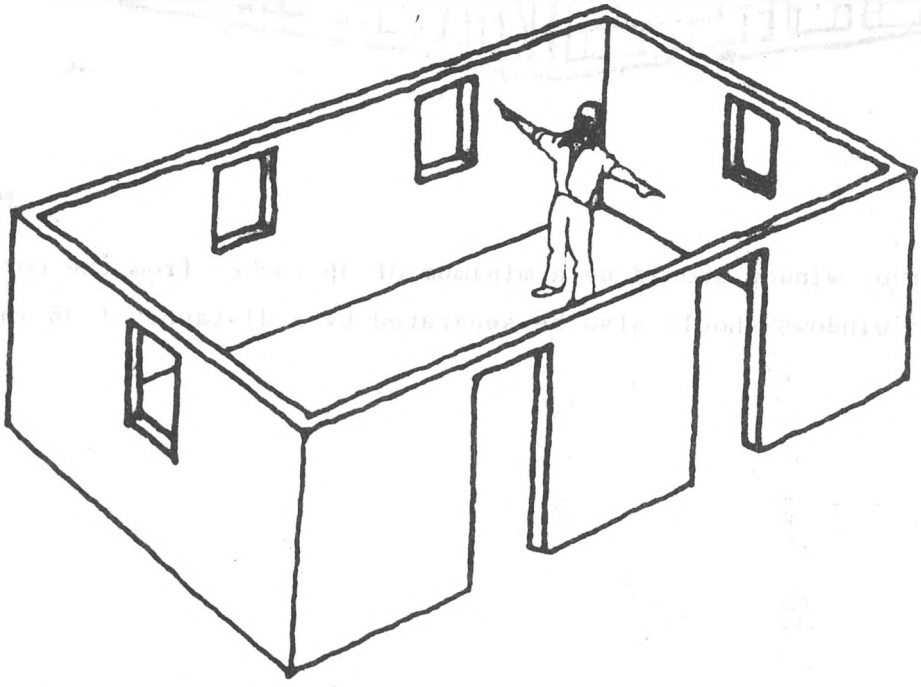
Build a reinforced concrete ring beam in the center of each wall.



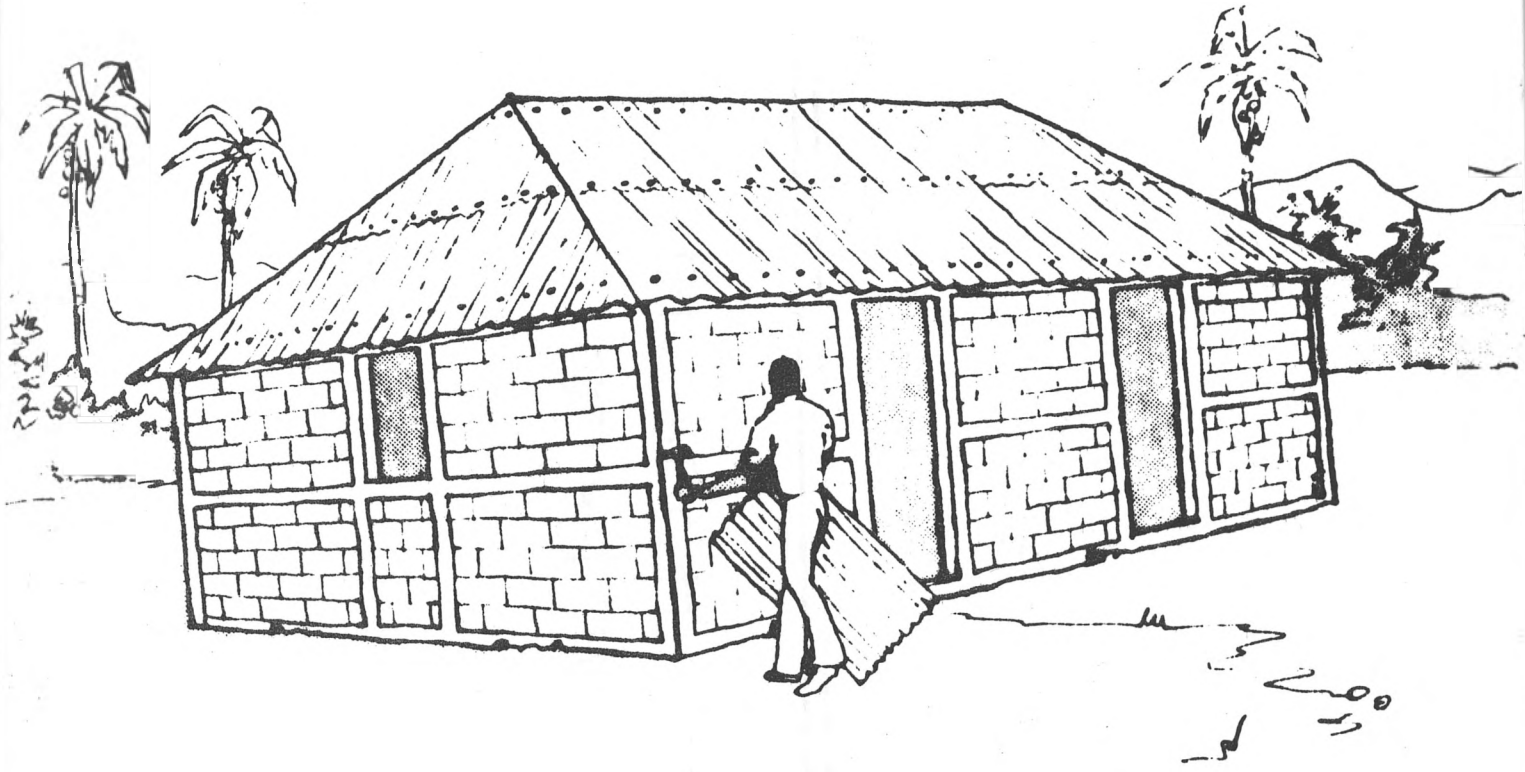
Each door or window should be a minimum of 36 inches from the corner. Doors and windows should also be separated by a distance of 36 inches.



Interior walls should be built columns and ring beams also, and they should be fastened securely to the outer walls. Doors should be placed in the center of the wall for maximum strength.



The house should be balanced by placing doors and windows opposite each other.

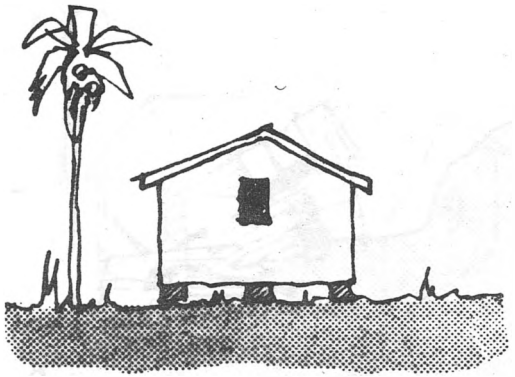


Fasten each galvanized sheet securely to the roof. Use a minimum of 12 nails for each sheet.

WIND-INDUCED FAILURES IN TRADITIONAL HOUSING

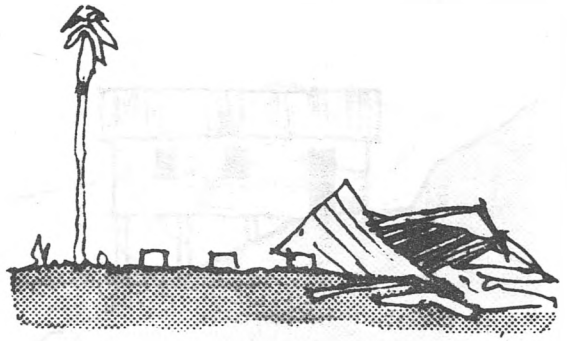
DOMINICA
DOMINICAN REPUBLIC

PROBLEM: A WOODEN HOUSE SET ON BLOCKS AND NOT ANCHORED TO THE GROUND



When a house is not anchored to the ground...

high winds can flow under the building...

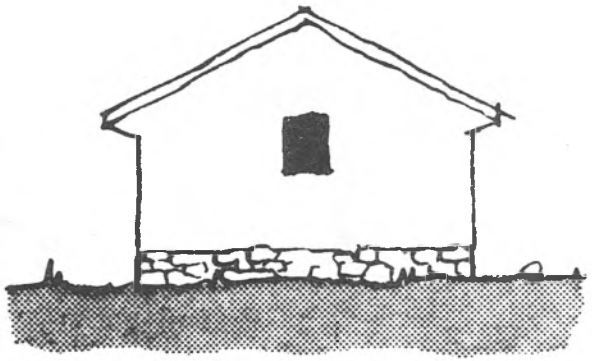


and blow it off the blocks.

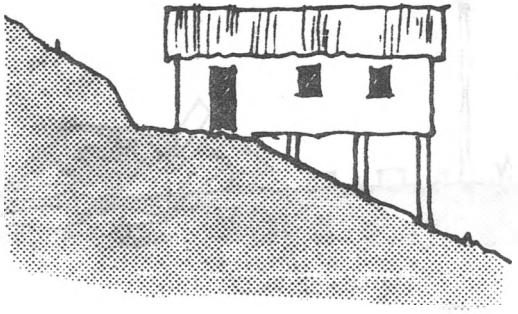
SOLUTION: ANCHOR THE WALLS TO THE GROUND

AND

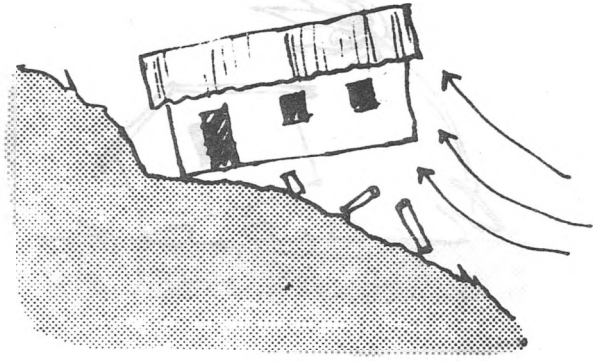
SET THE HOUSE ON A FOUNDATION



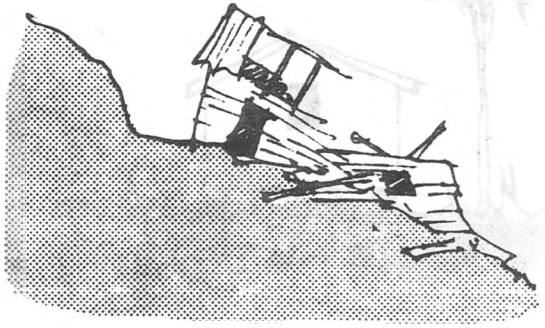
PROBLEM: HOUSES ON STILTS ON HILLSIDES



When a house is built on stilts on the side of a hill...

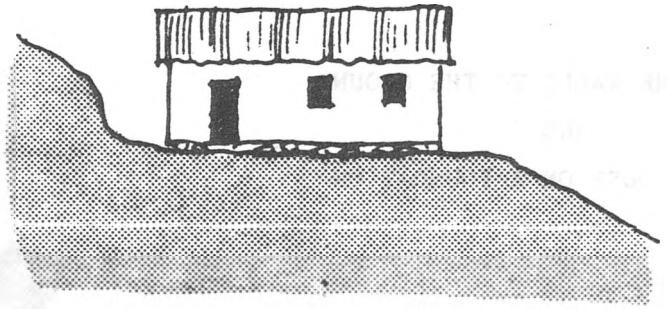


high winds can be deflected up the side of the hill...

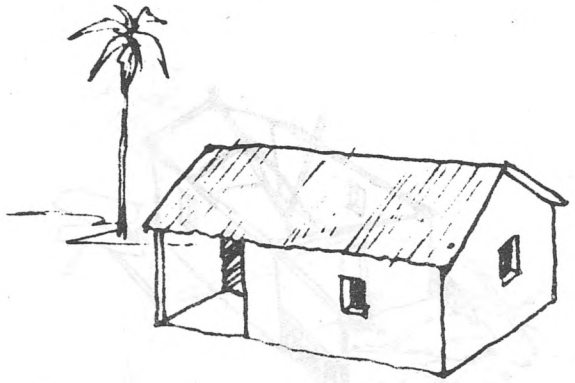


and blow it off the stilts.

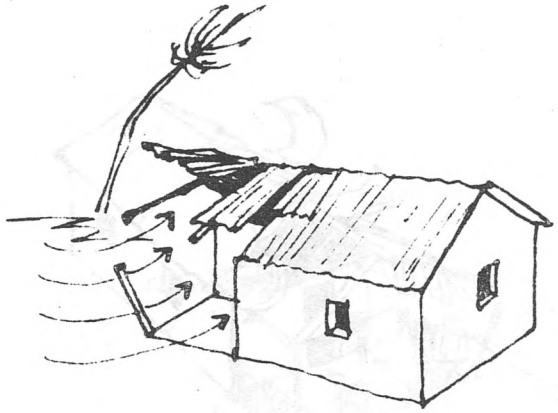
SOLUTION: EXCAVATE A PLATFORM FOR THE HOUSE



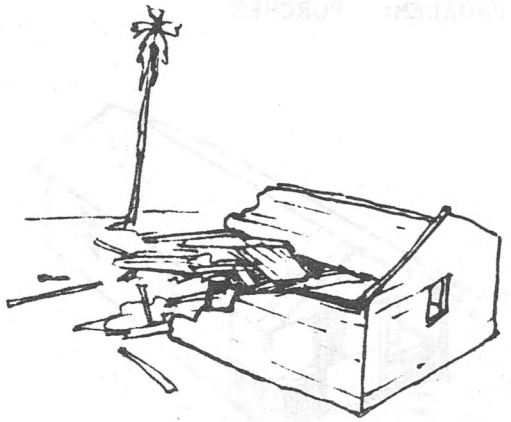
PROBLEM: OPEN HALF-PORCHES



When houses have open half-porches...

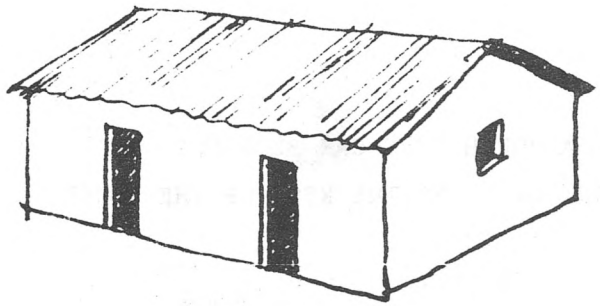


high winds can get under the roof...

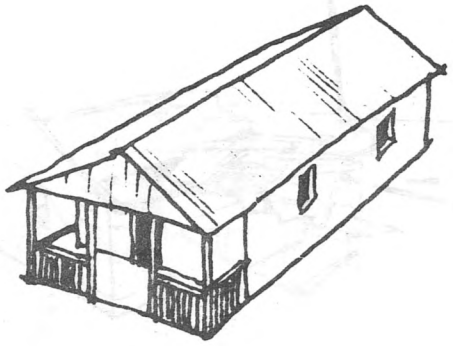


and lift the roof off the walls.

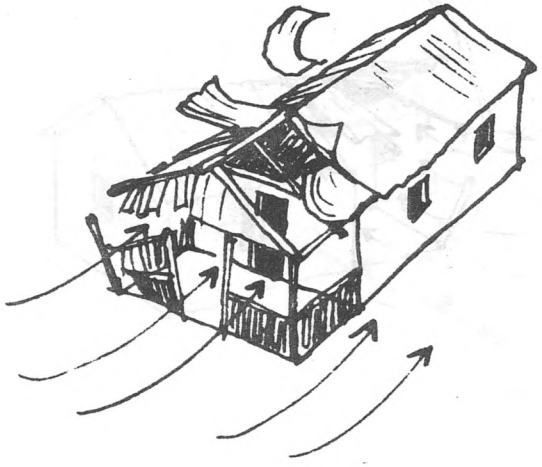
SOLUTION: DO NOT BUILD A HALF-OPEN PORCH



PROBLEM: PORCHES



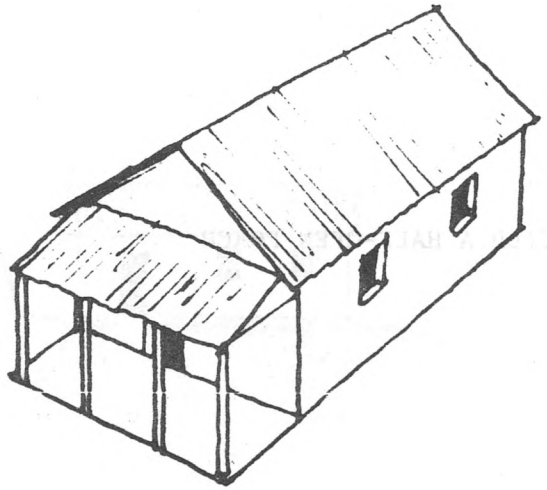
When houses have open porches...



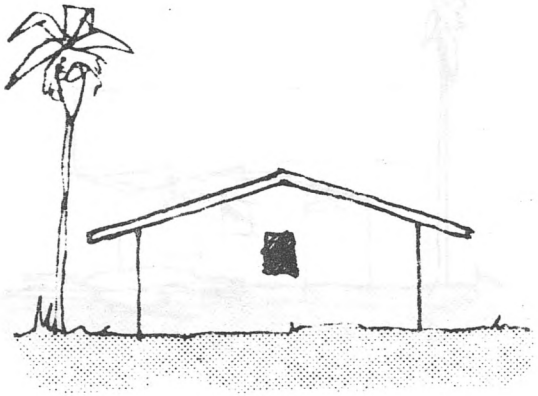
high winds can be deflected upward...

and lift the roof off.

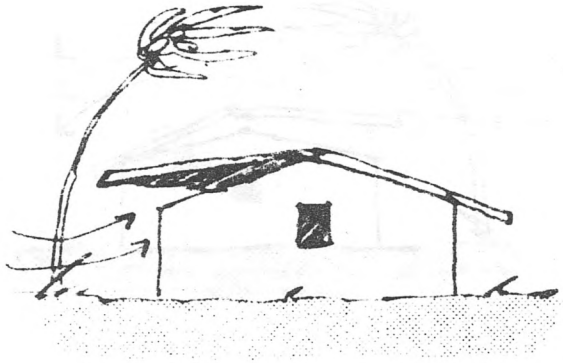
SOLUTION: BUILD A PORCH THAT CAN BLOW OFF
WITHOUT DAMAGING THE REST OF THE HOUSE



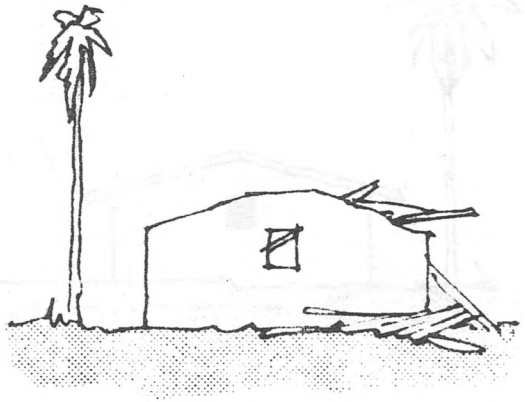
PROBLEM: LARGE OVERHANGS



A roof with a large overhang...



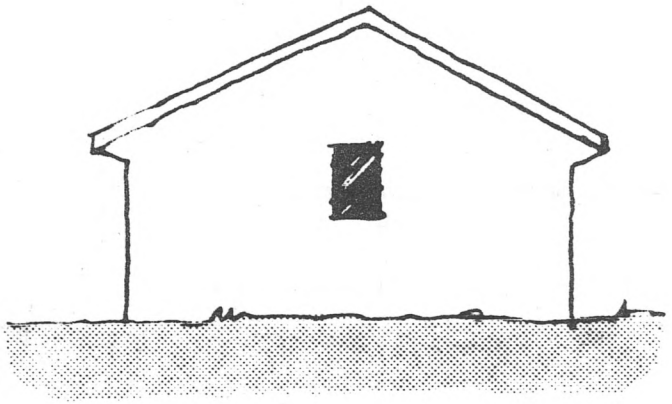
allows wind to push upward on the edge of the roof...



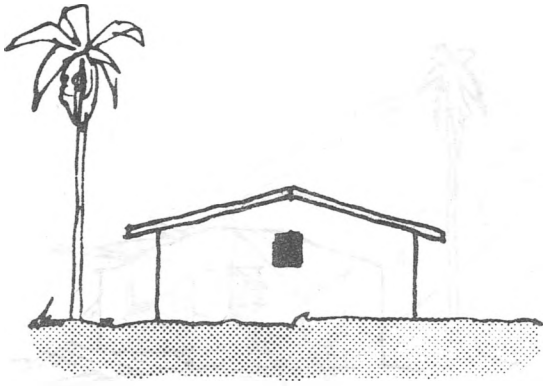
and lift the roof off.

SOLUTIONS: 1) KEEP OVERHANGS TO LESS THAN 18" (46 CM)

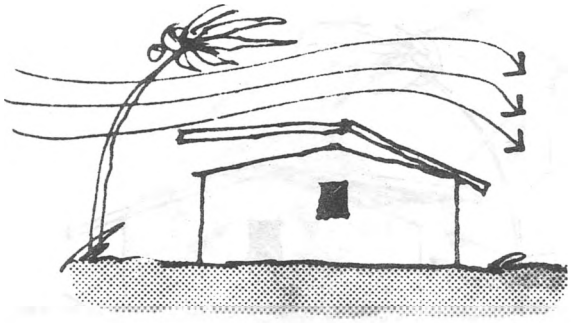
2) SEAL THE EAVES TO PREVENT AIR FROM BEING TRAPPED BETWEEN THE WALL AND THE ROOF.



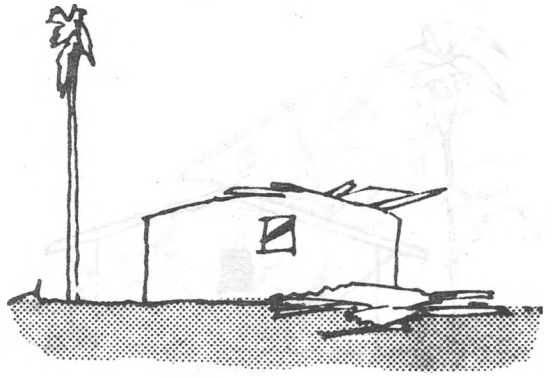
PROBLEM: LOW-PITCHED ROOFS



Houses with low-pitched roofs...

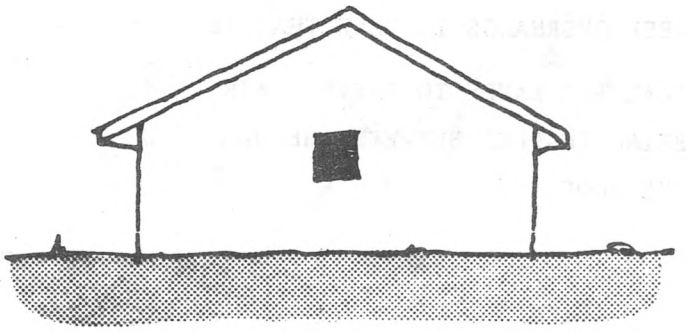


create lift on the top of the roof...

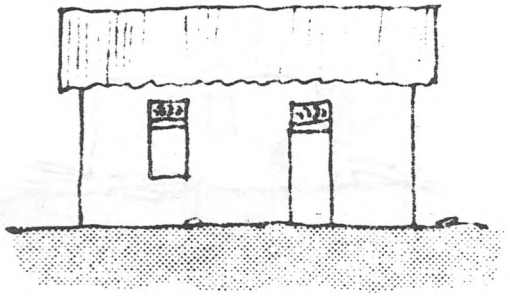


which lifts the roof off the house.

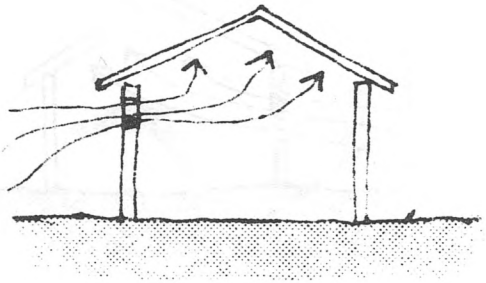
SOLUTION: BUILD ROOFS WITH A PITCH OF 30°-45°



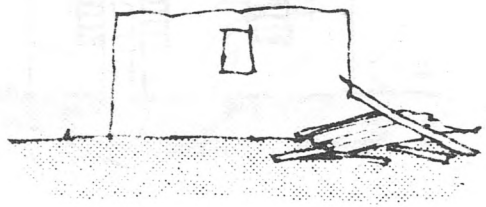
PROBLEM: TRANSOMS



Transoms allow wind to enter the house...

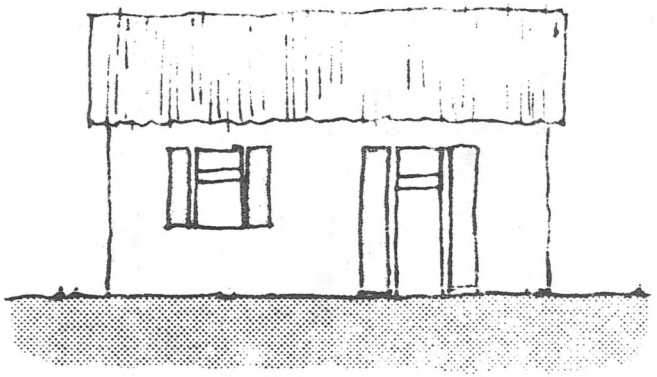


adding to the pressure on the inside...

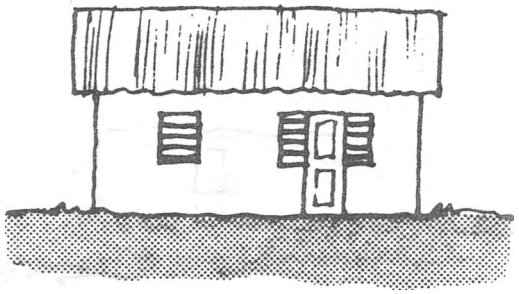


which causes the house to collapse.

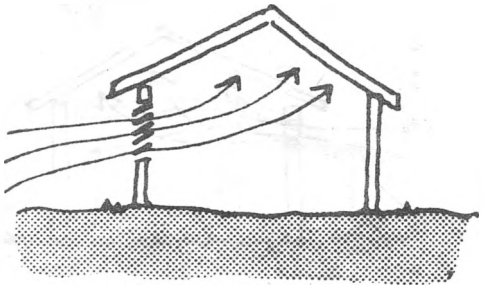
SOLUTION: SHUTTERS



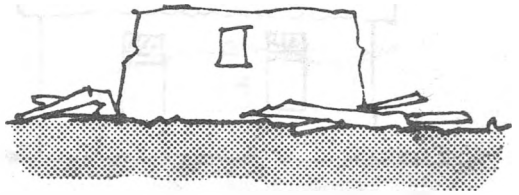
PROBLEM: LOUVERED WINDOWS AND DOORS



Louvered windows and doors...

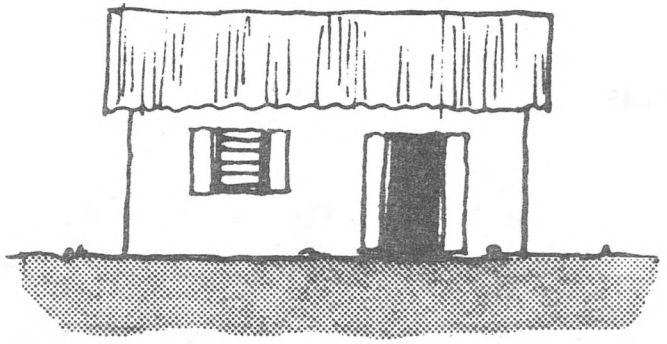


allow wind to enter the house...

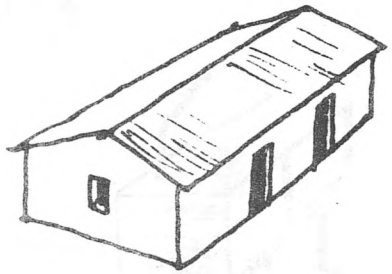


which adds to the pressures pushing out on the walls and roof.

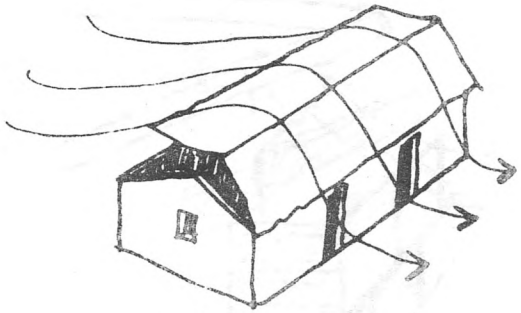
SOLUTION: SHUTTERS FOR DOORS AND WINDOWS



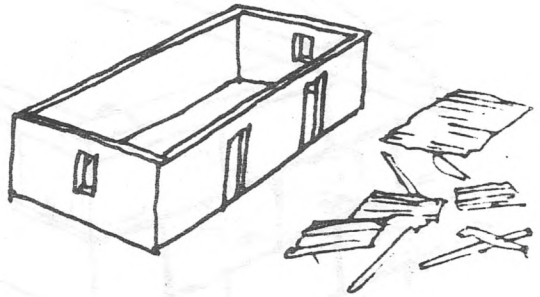
PROBLEM: GABLED ROOFS



Gabled roofs allow the wind to pass evenly over the surface...

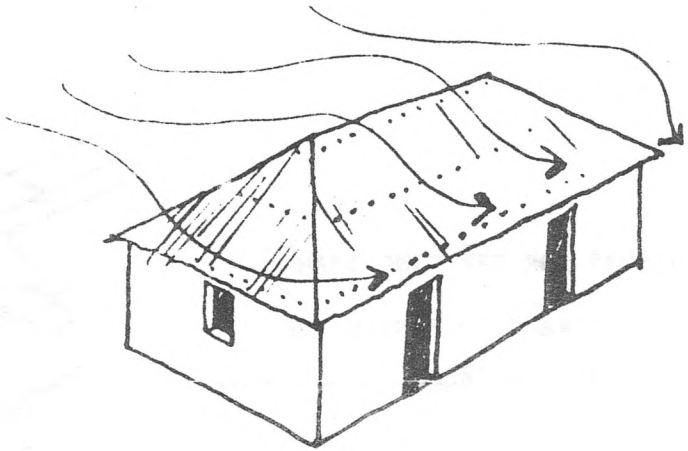


creating undisturbed lift which pulls upward...

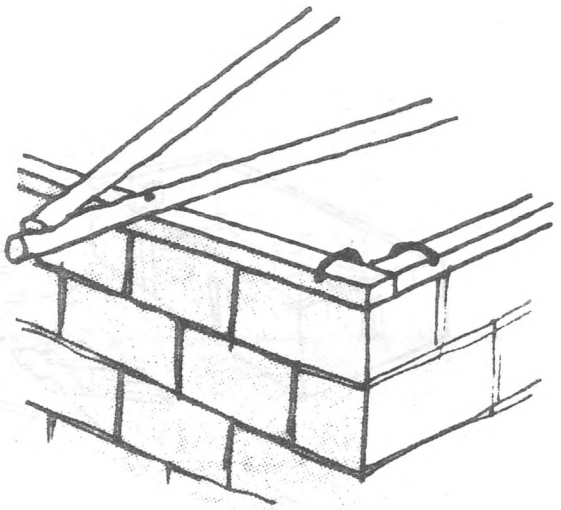


and lifts the roof off the walls.

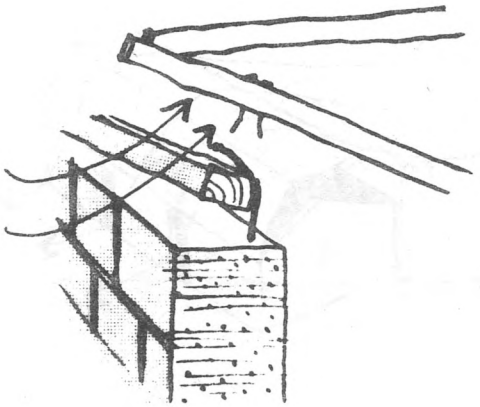
SOLUTION: USE A HIP ROOF CONFIGURATION



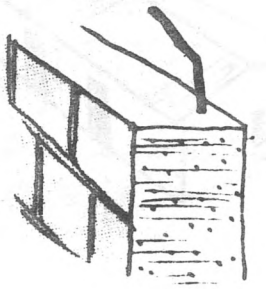
PROBLEM: POOR CONNECTION BETWEEN ROOF AND BLOCK WALL



A roof fastened to a wall in this manner...



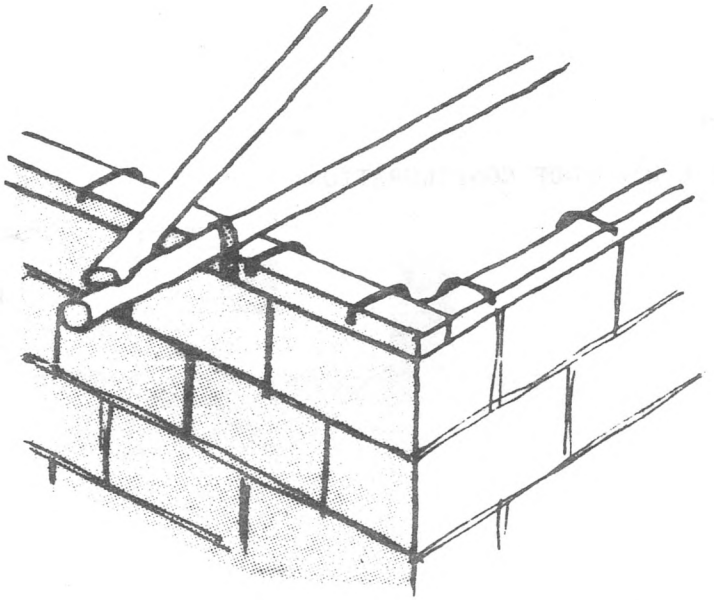
cannot resist the lifting forces...



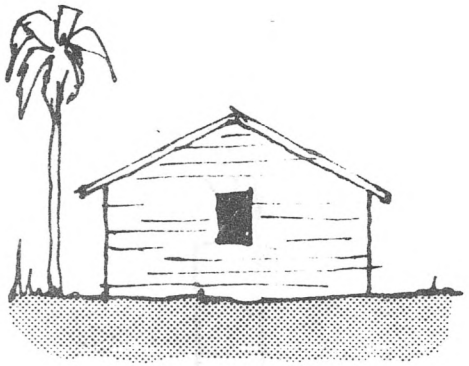
and the roof will blow off.

SOLUTION: 1) USE ANCHORS FOR THE RING BEAM

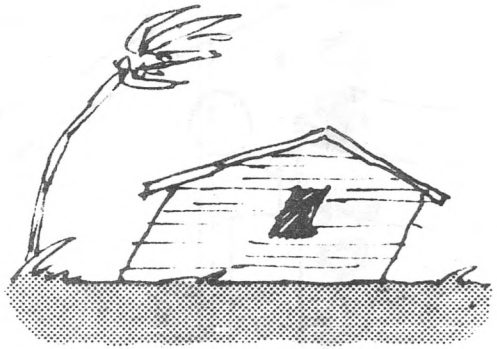
2) USE METAL STRAPS TO FASTEN THE TRUSS TO THE RING BEAM



PROBLEM: FAILURE OF WOODEN HOUSES TO RESIST FORCES ON THE WALLS



Wooden houses that are not properly braced and tied together...



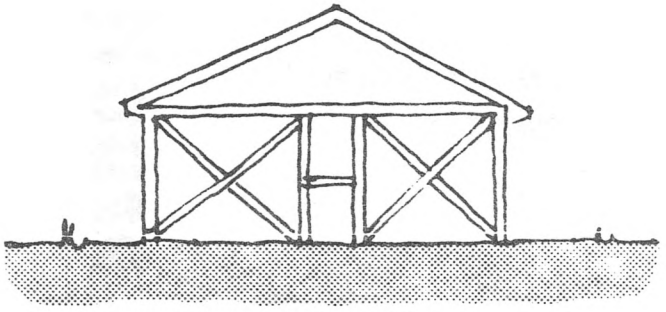
cannot resist very high winds...

and are likely to collapse.

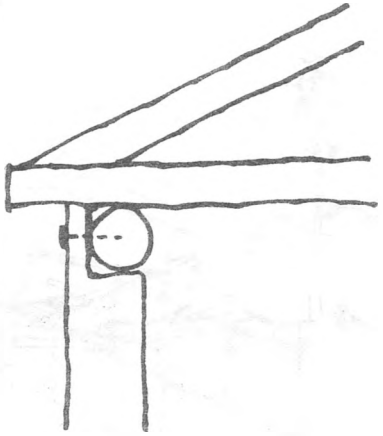
SOLUTIONS: 1) CROSS-BRACING

2) BETTER ANCHORING

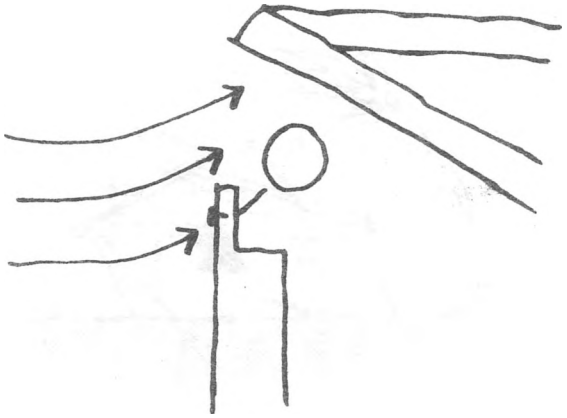
3) TREATING THE WOOD



PROBLEM: WEAK CONNECTIONS BETWEEN ROOF FRAME AND WALL COLUMNS



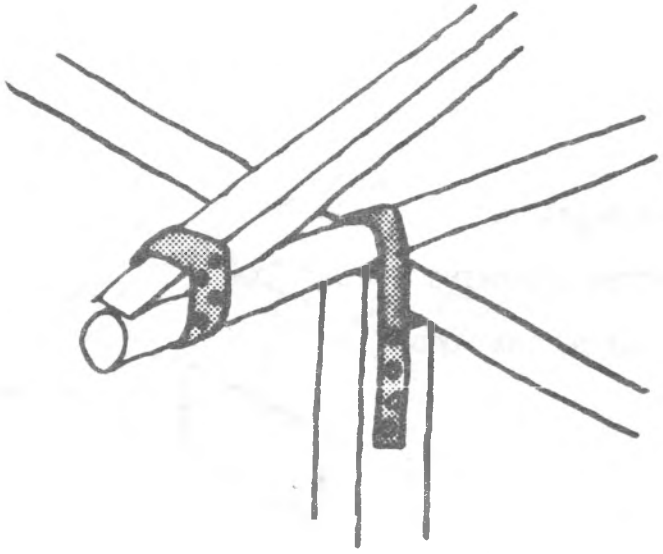
A roof fastened to a wall in this manner...



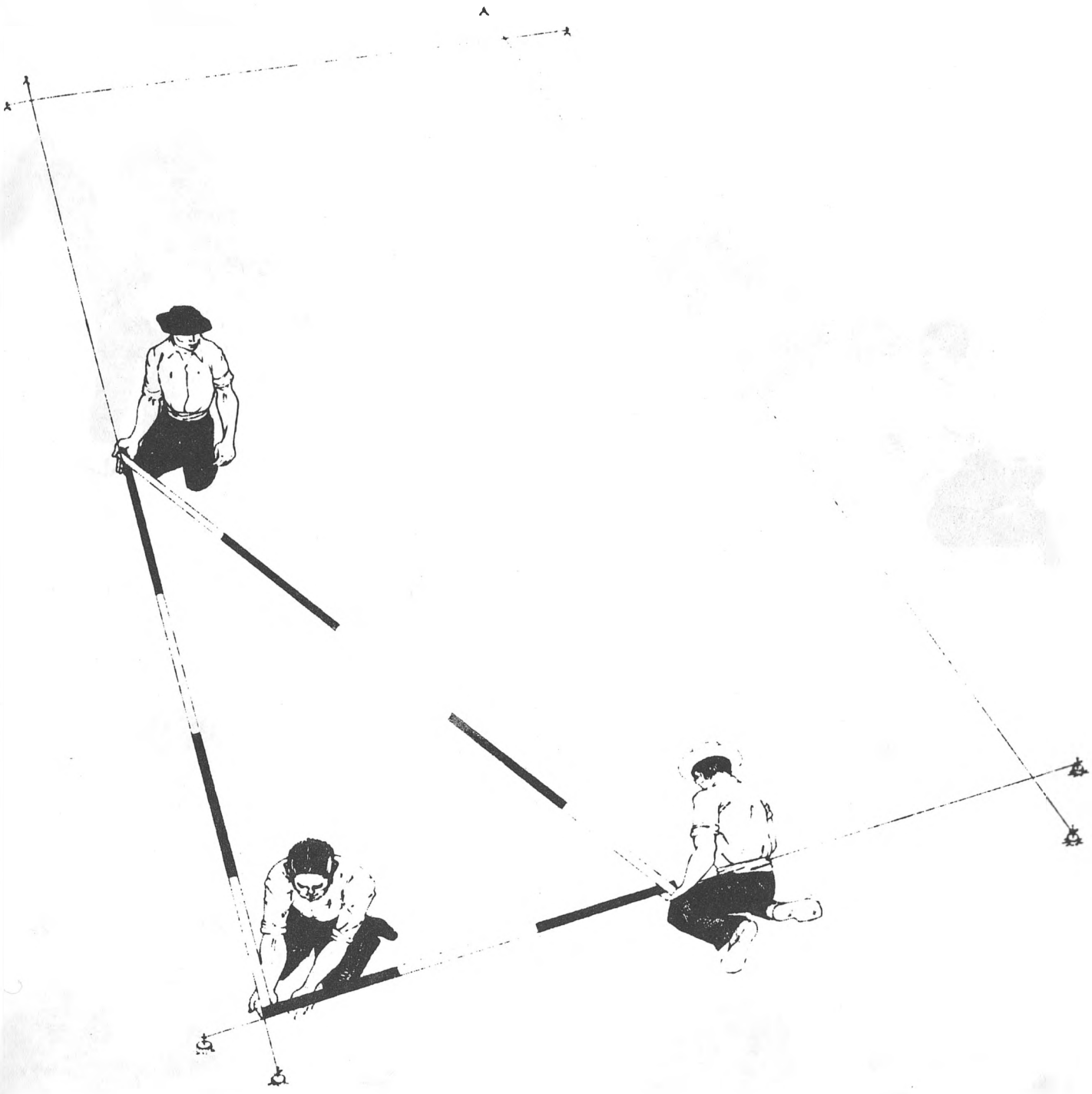
cannot resist the lifting forces of the wind...

and the roof will blow off.

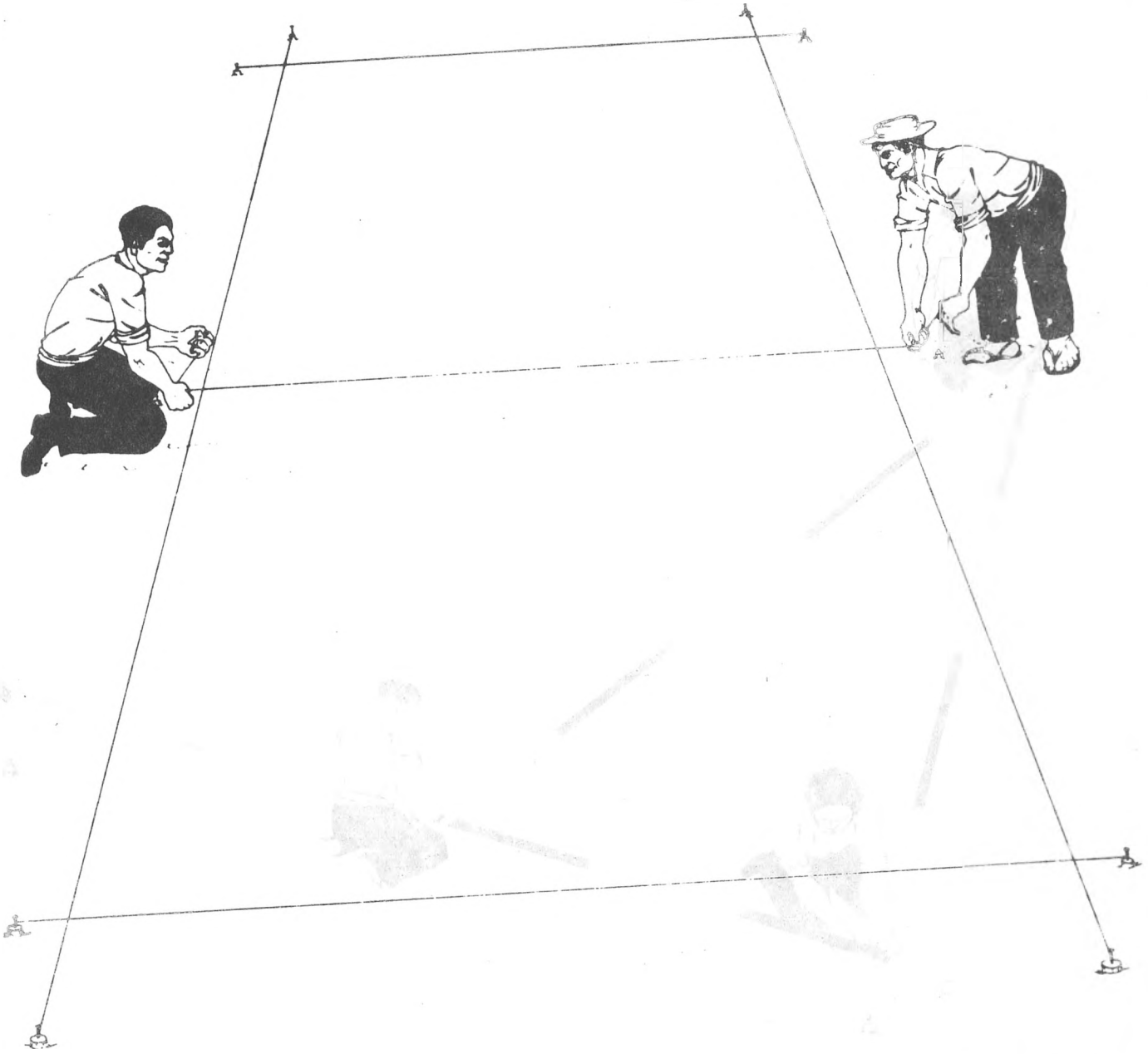
SOLUTION: USE METAL STRAPS TO REINFORCE THE CONNECTION



How to Lay Out a House



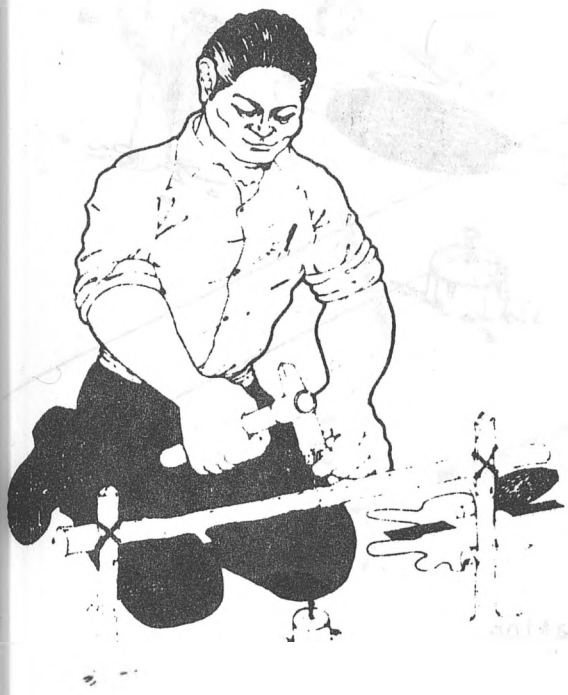
Using string, mark the outline of the house. Use the "3-4-5" method to make sure the string is square.



Tie a string to mark where the inside wall will go. Check to make sure it is perpendicular to the outside wall.

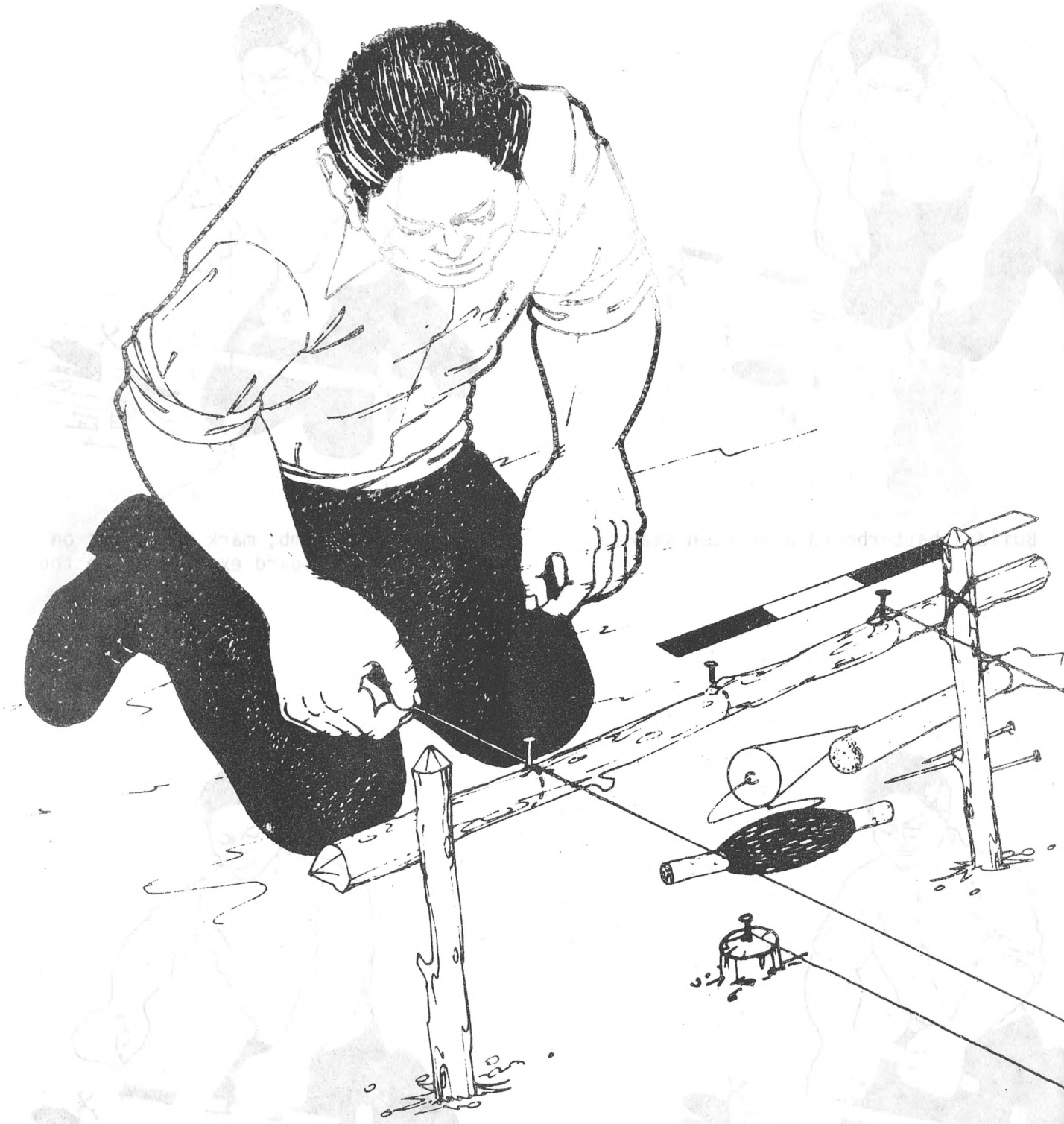
Build a batterboard over each stake.

Using a plumb, mark the point on the batterboard exactly above the nail.

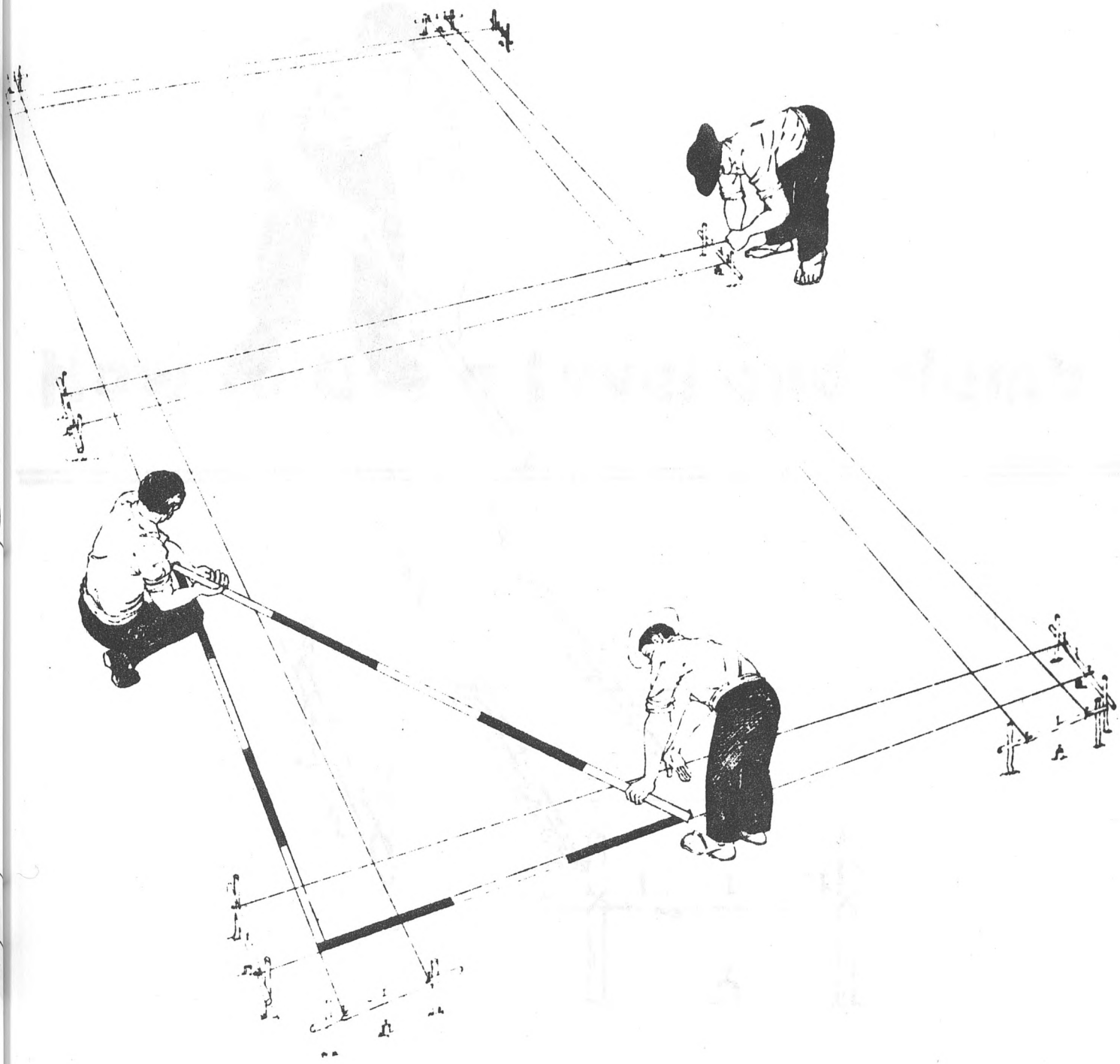


Put a nail in the batterboard at the mark.

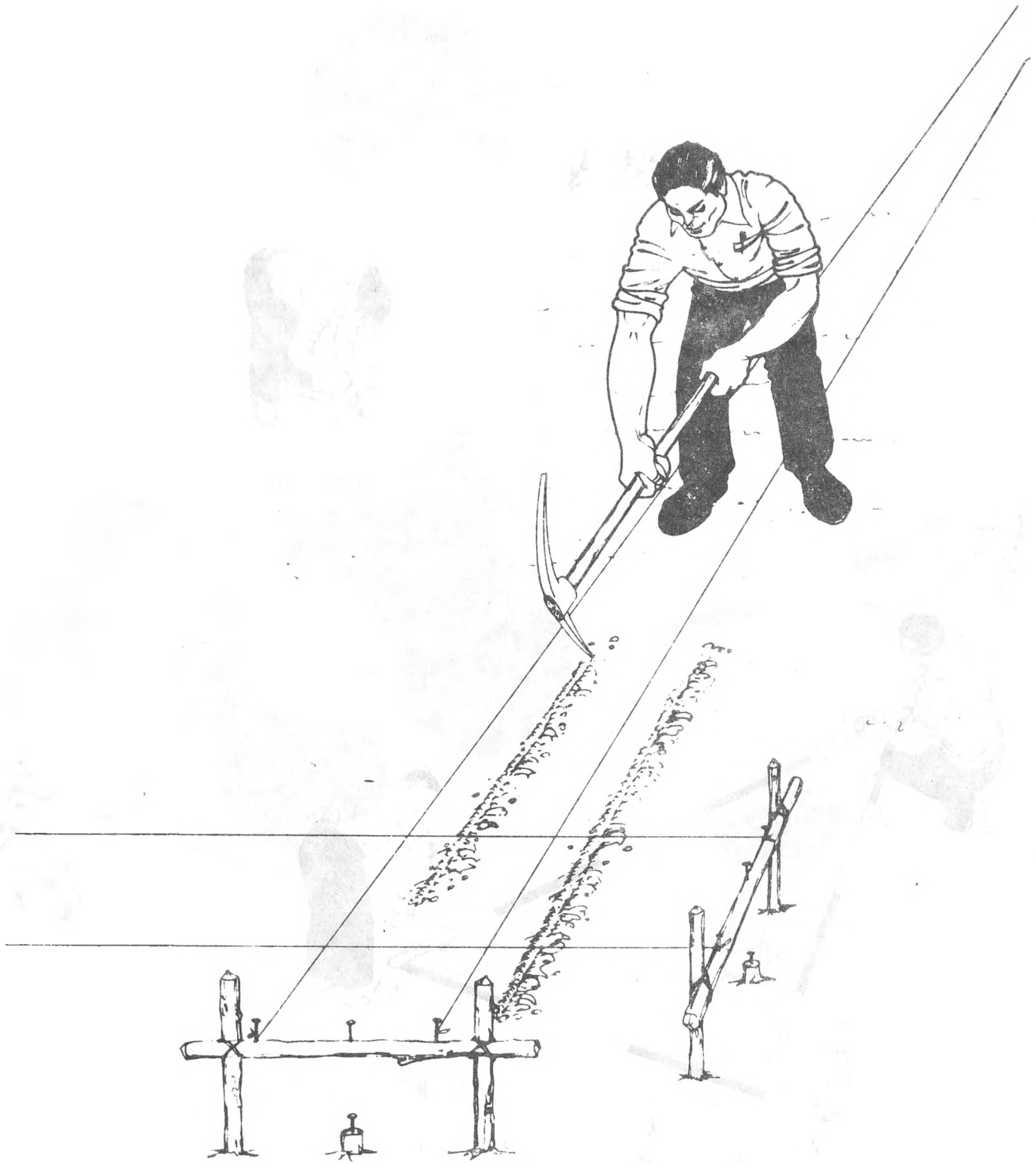
Using the nail as the center point, mark the width of the foundation on the batterboard.



Tie string over the marks to outline the foundation.



Use the "3-4-5" method to check that the new strings are square.



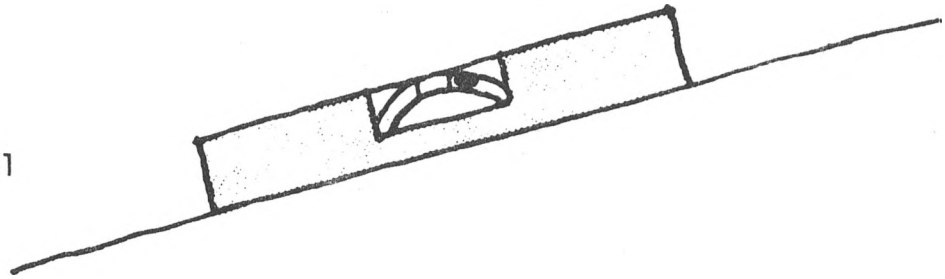
Using the string as a guide, mark the line of the trench for the foundation.

How to Use a Level and Plumb

THE LEVEL

If the bubble in the level is not centered, the thing being checked is not level.

Not Level

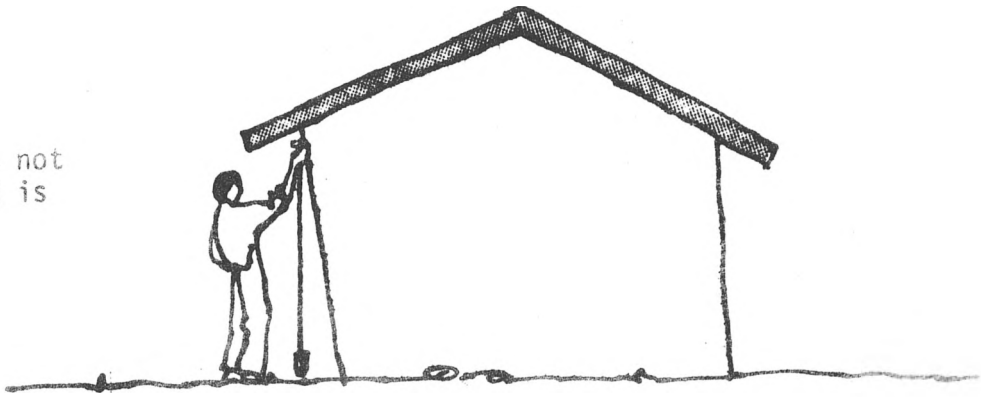


Level

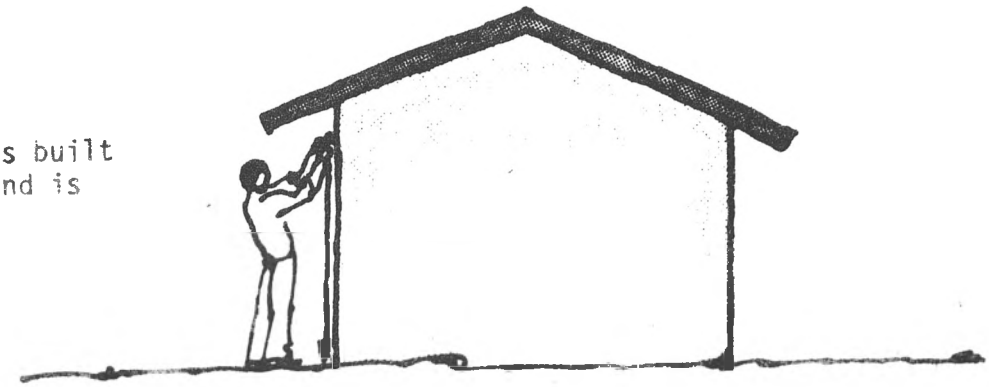
THE PLUMB

A plumb is used to determine if a wall is built correctly.

This wall is not straight and is dangerous.



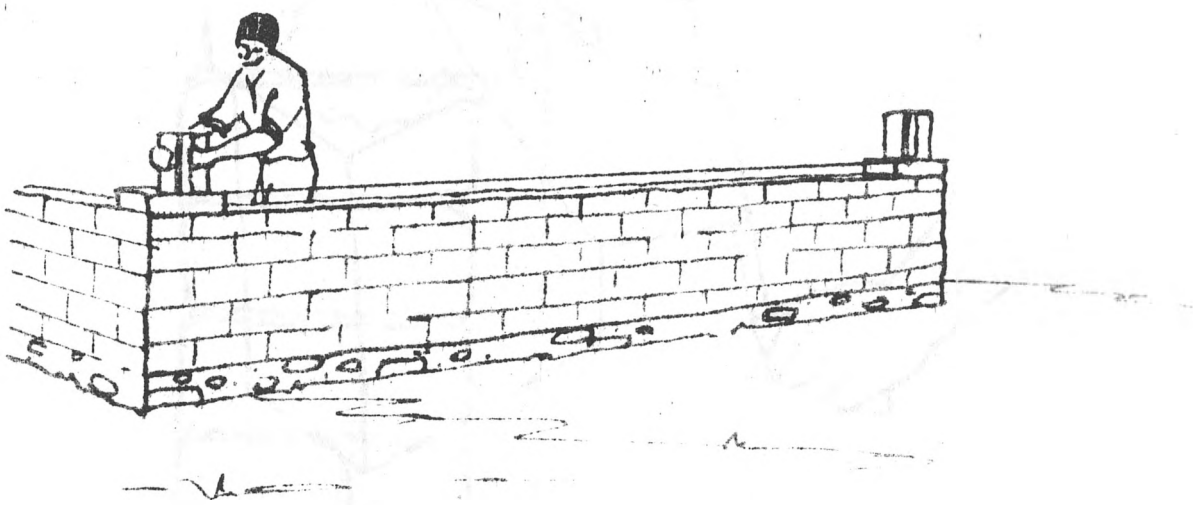
This wall is built correctly and is safe.



How to Build a Straight and Level Wall

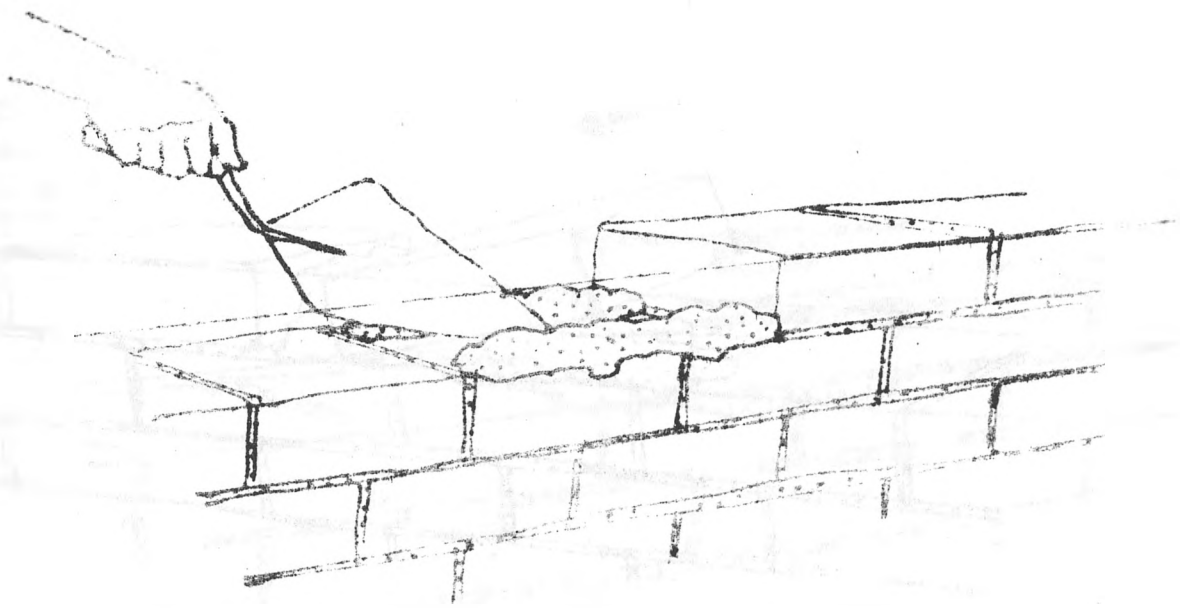
HOW TO BUILD A LEVEL AND PLUMB WALL

Step 1



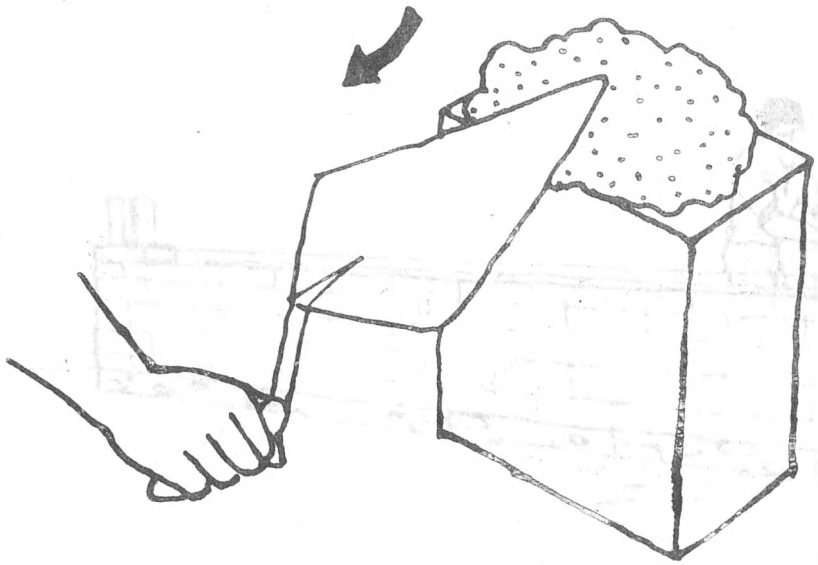
Tie a string from corner to corner to use as a guide to place the adobes in a straight line.

Step 2



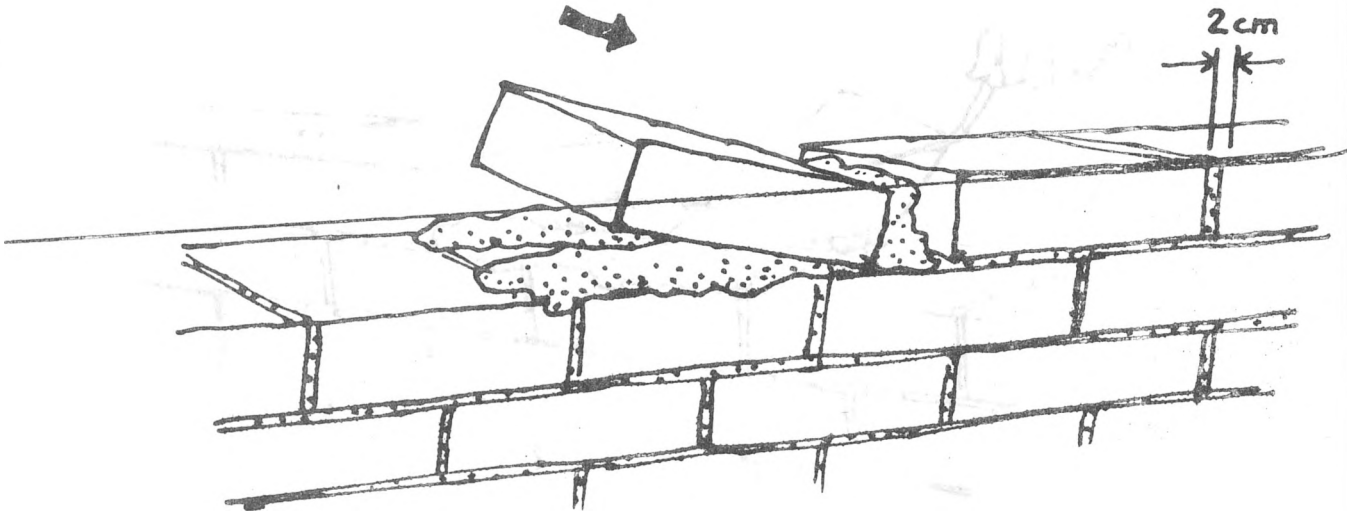
Put the mortar on the wall like this.

Step 3



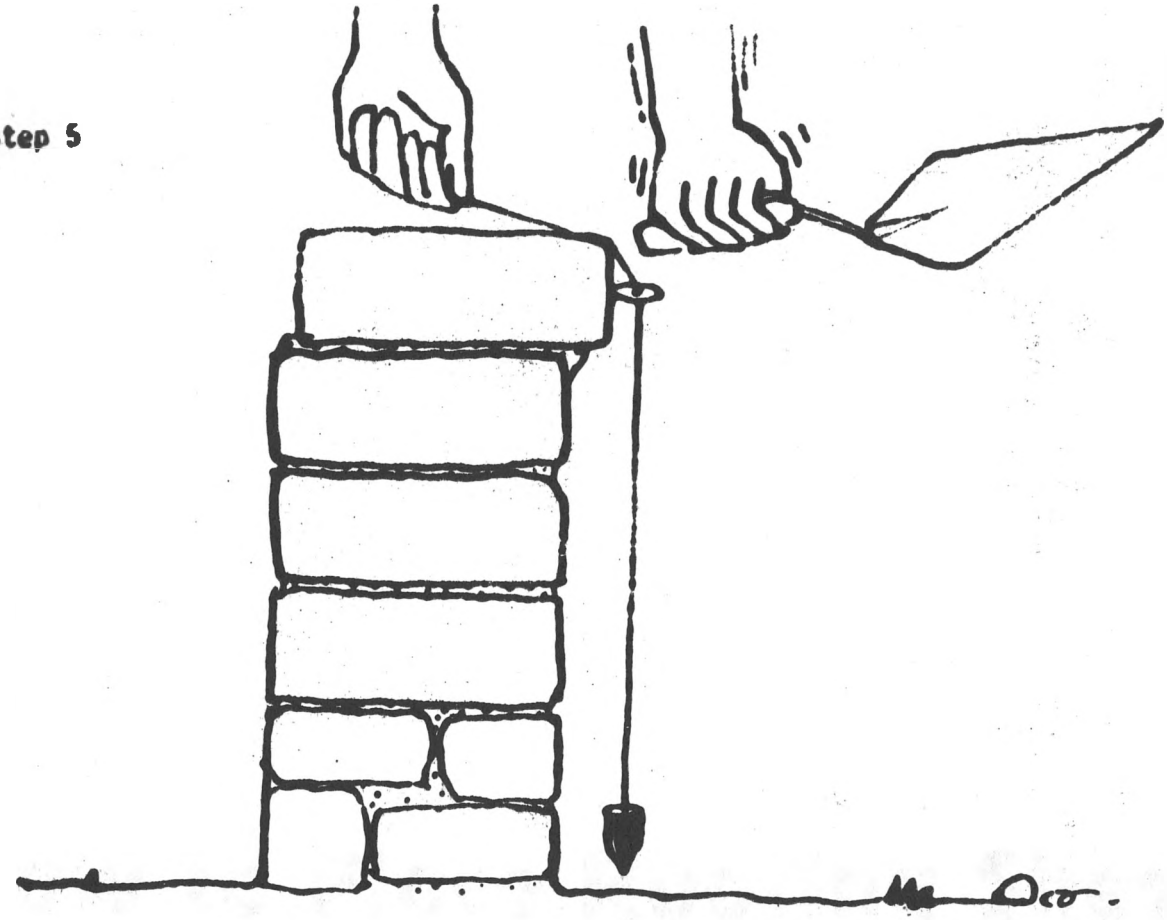
Put mortar on the end of an adobe.

Step 4



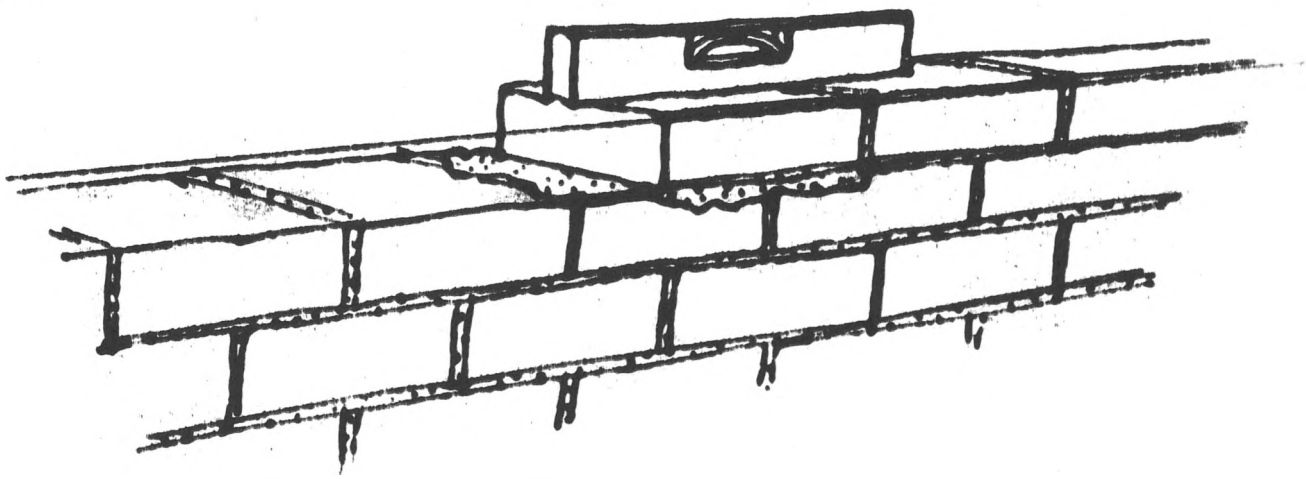
Put the adobe on the wall.

Step 5

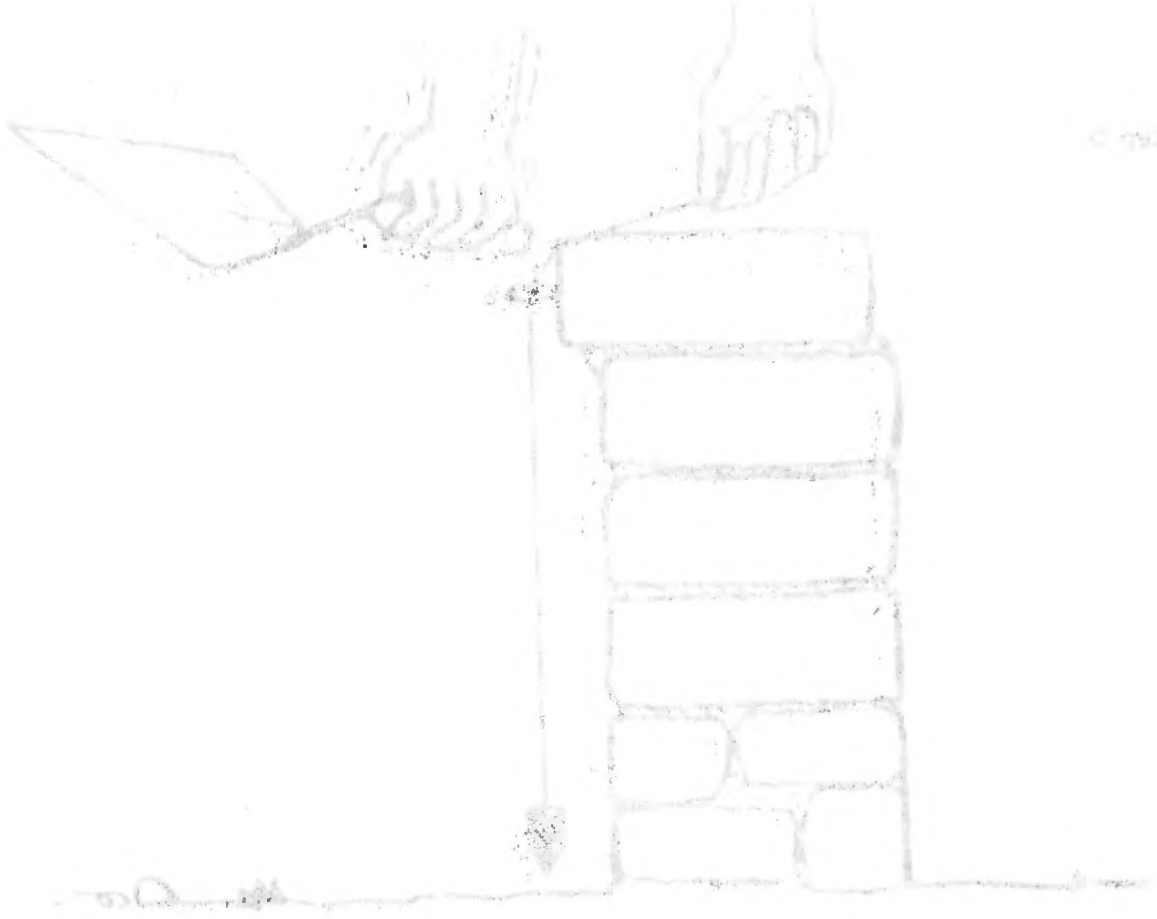


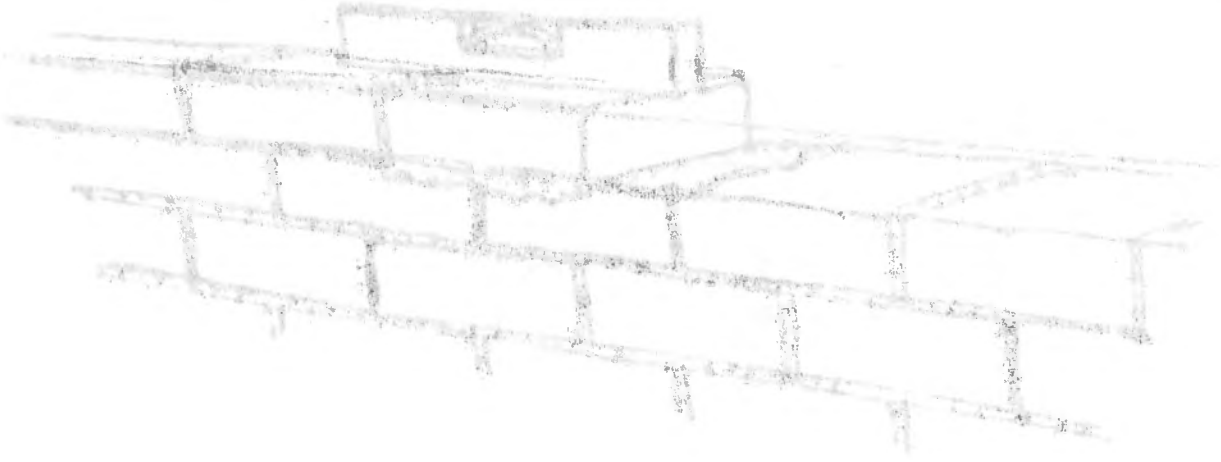
Using a plumb, tap the adobe into place until it is in line with the rest of the wall.

Step 6



Use a level to make sure the adobe is flat.



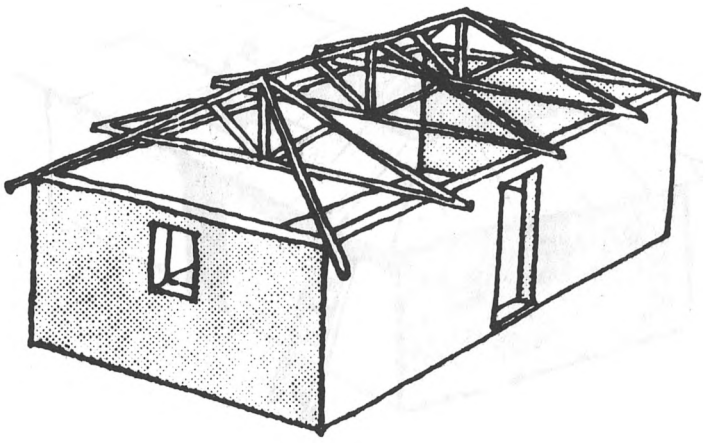


How to Place Roofing Sheets

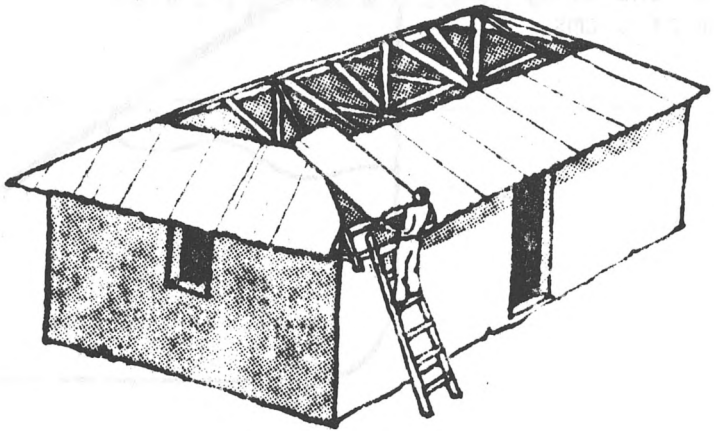
How to Place Roofing Sheets

HOW TO BUILD A SHEET ROOF

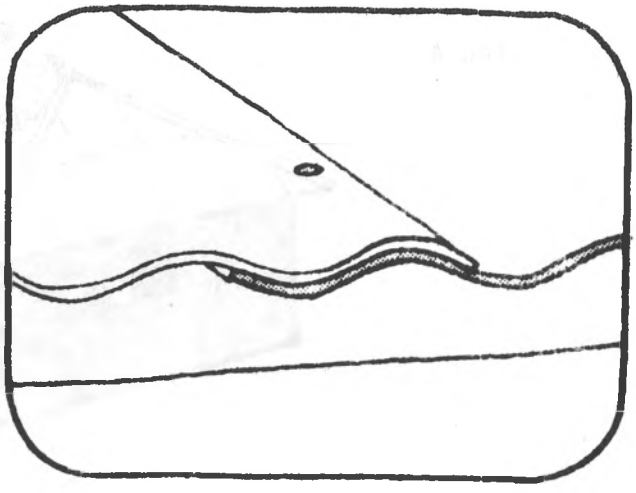
Step 1



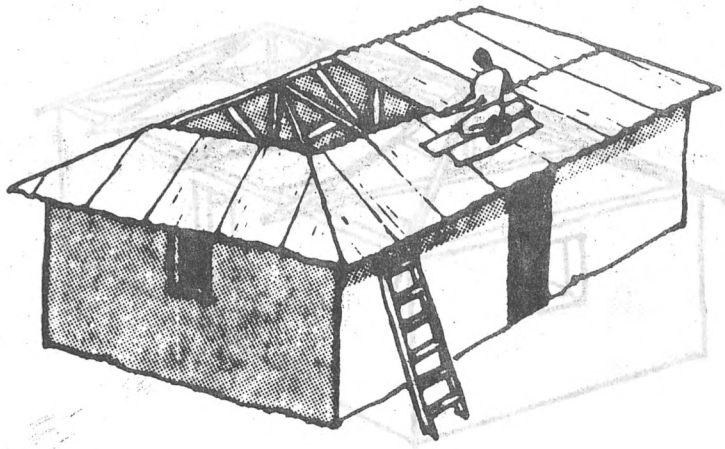
Step 2



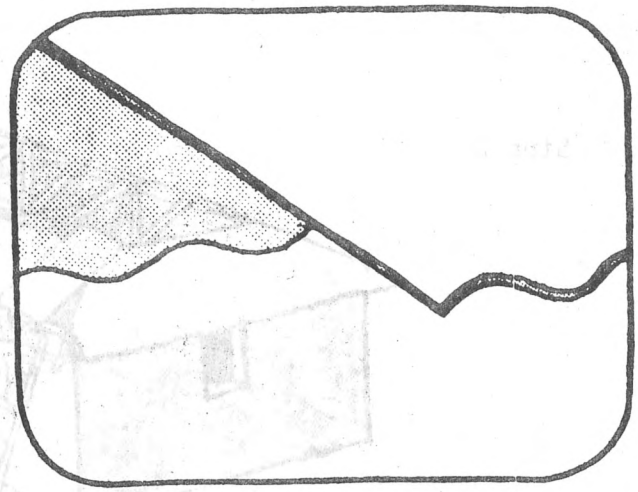
Overlap the sheets
one and one-half canals.



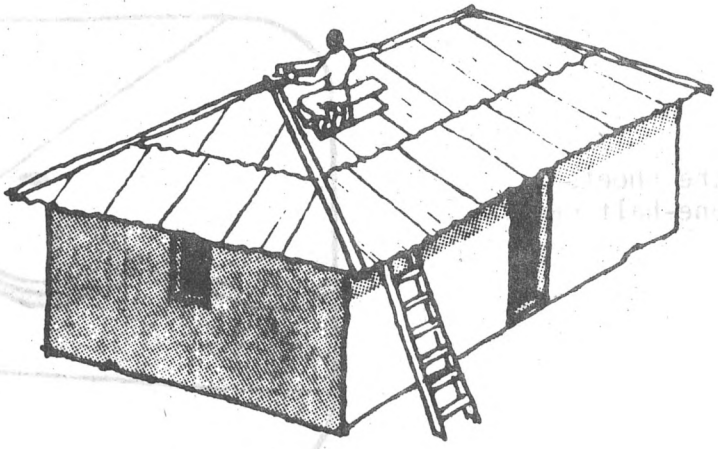
Step 3



Overlap the second layer of sheets a minimum of 5 cms.



Step 4



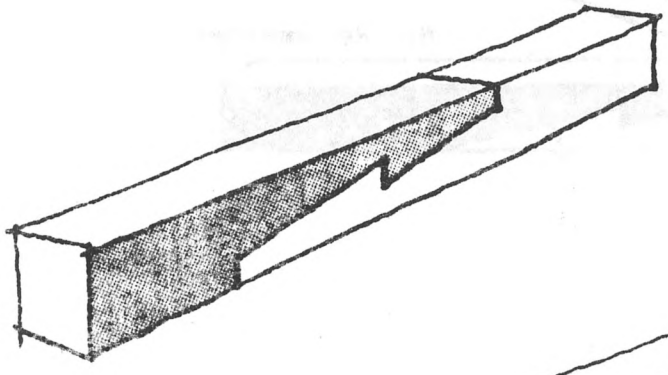
Empalmes

Empalmes

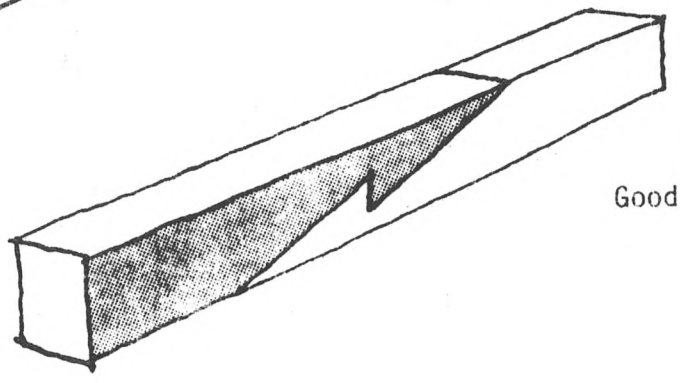
JOINTS

These are the best joints:

1. The "Cadena"



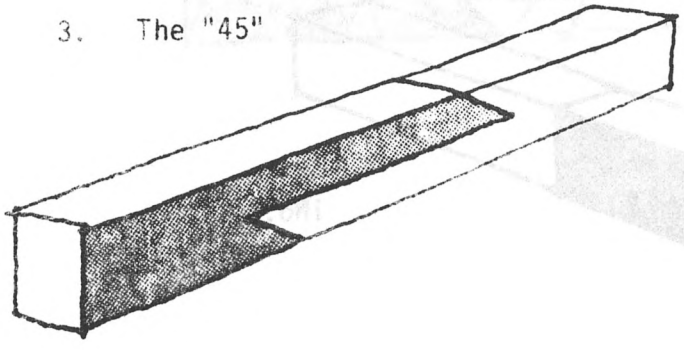
Best



Good

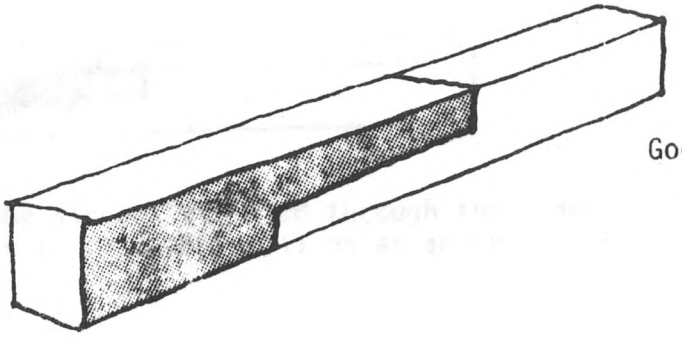
2. The "Double Tacón"

3. The "45"



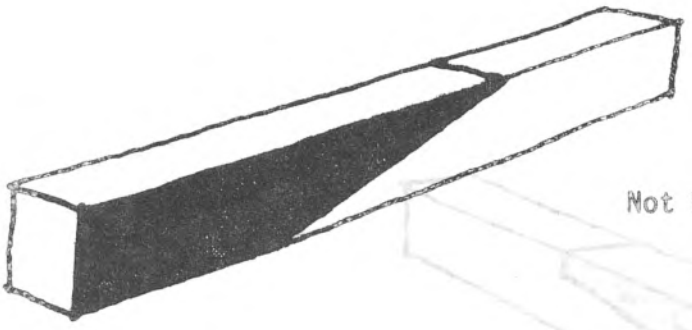
Good

4. The "Escuadra"

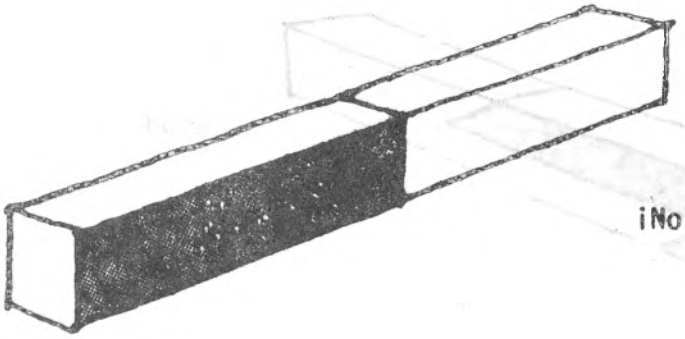


Good

FALSE JOINTS

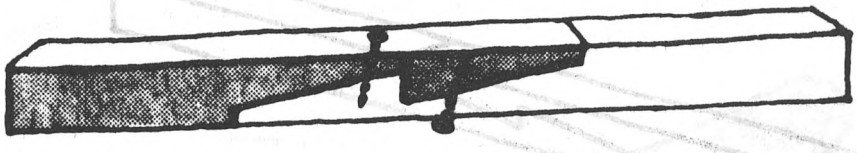


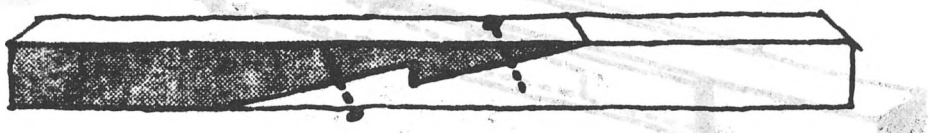
Not Recommended

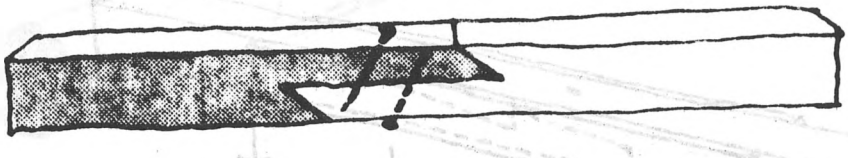


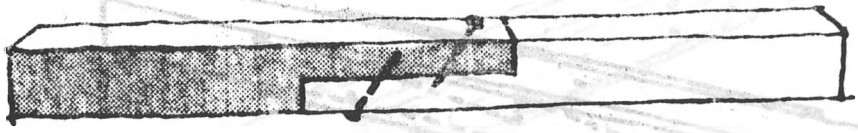
¡No!

HOW TO NAIL EACH TYPE OF JOINT





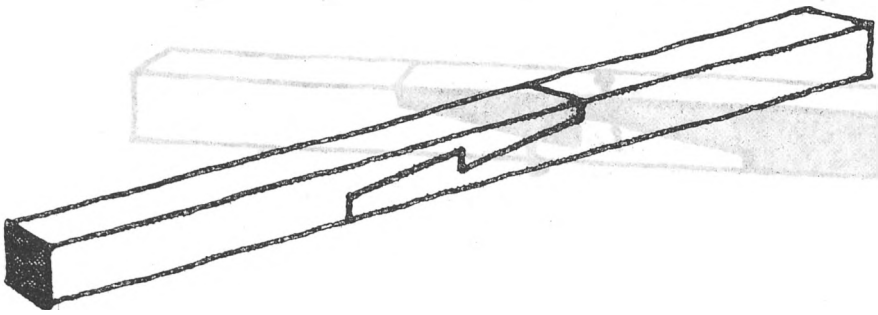




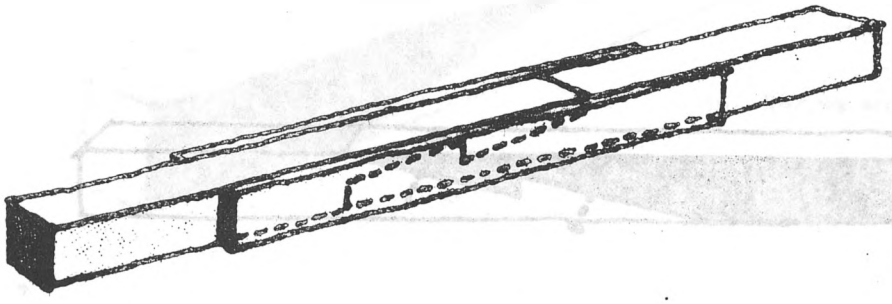
Nails should not pass from one side of the wood through the other -- it will split the wood. It is better to place the nail on an angle.

HOW TO USE GUSSETS TO SUPPORT THE JOINT

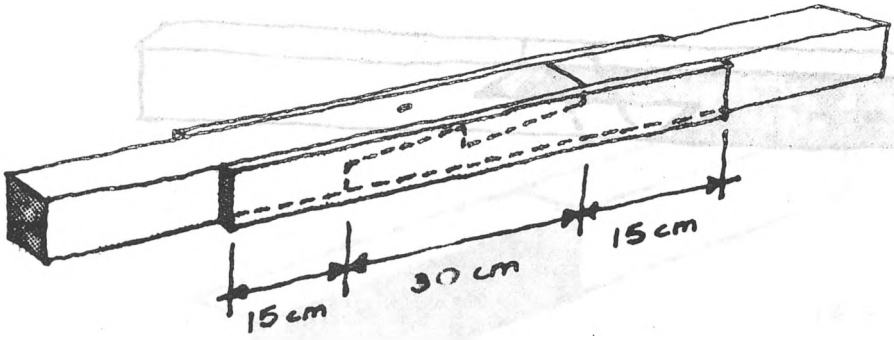
1.



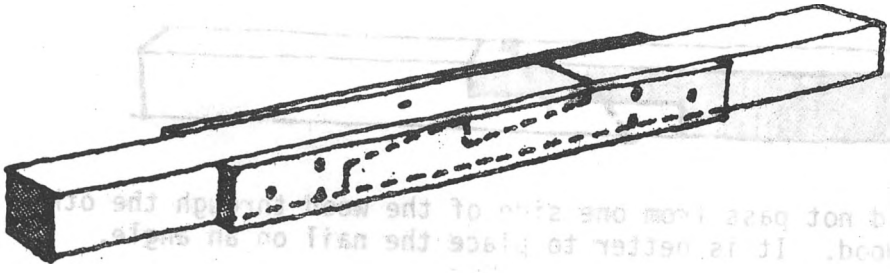
2.



3.



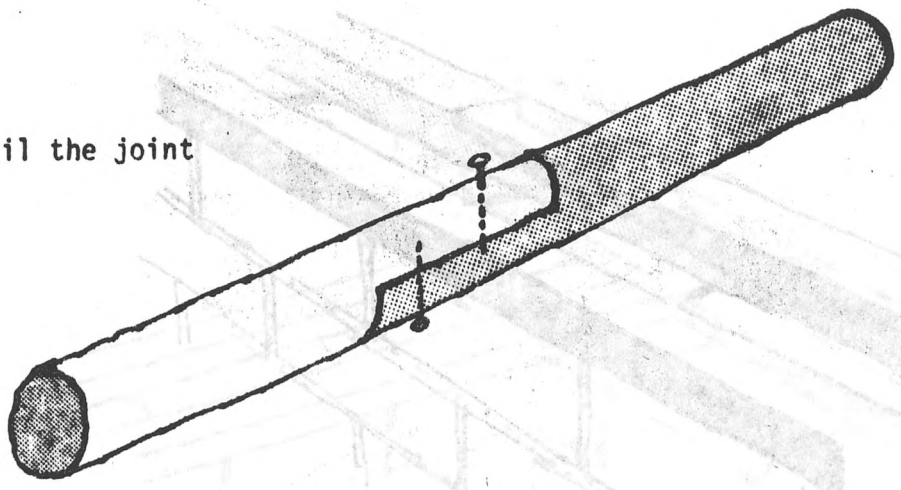
4.



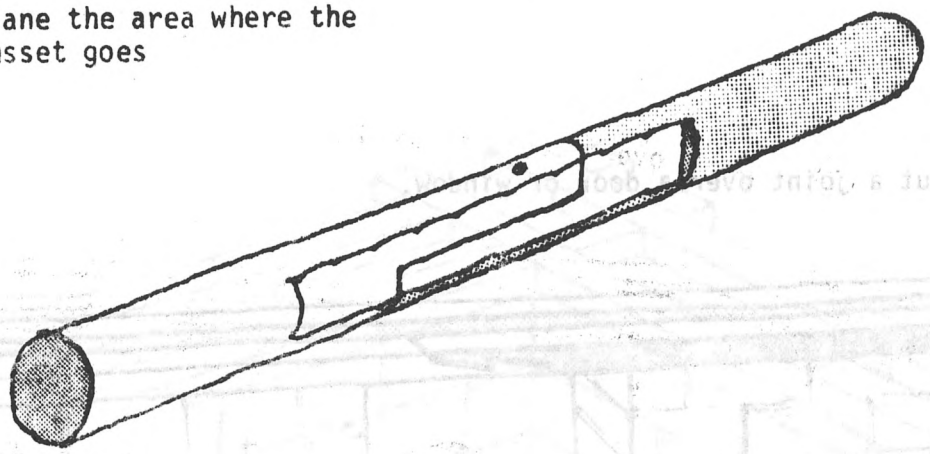
It is very important to reinforce the joint with gussets on both sides of the joint.

HOW TO MAKE JOINTS USING ROUND POLES

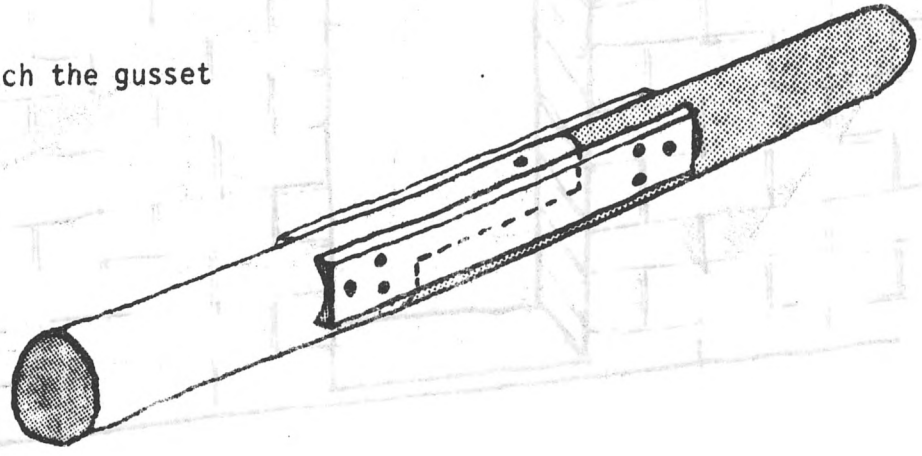
1. Nail the joint



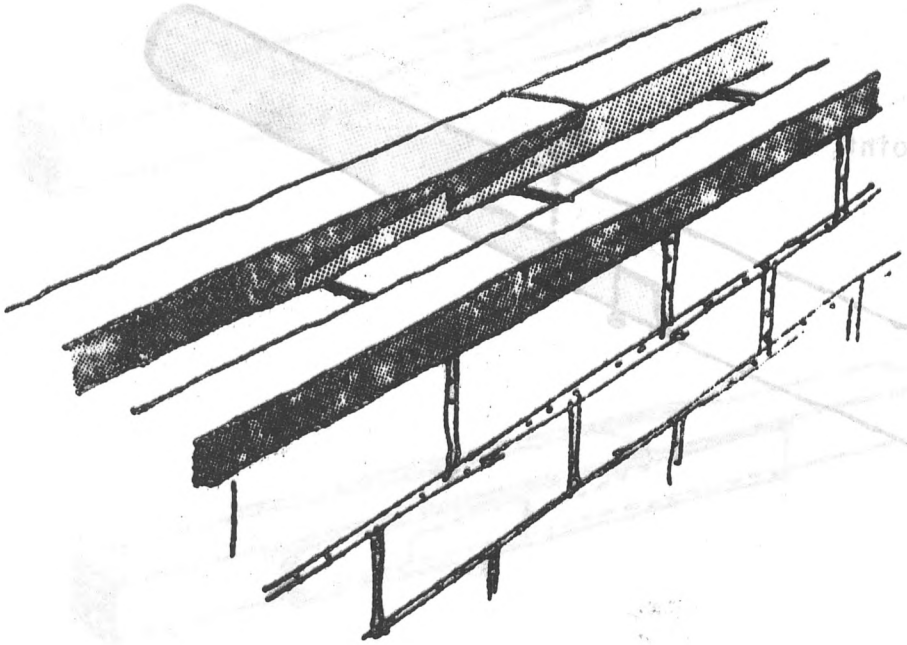
2. Plane the area where the gusset goes



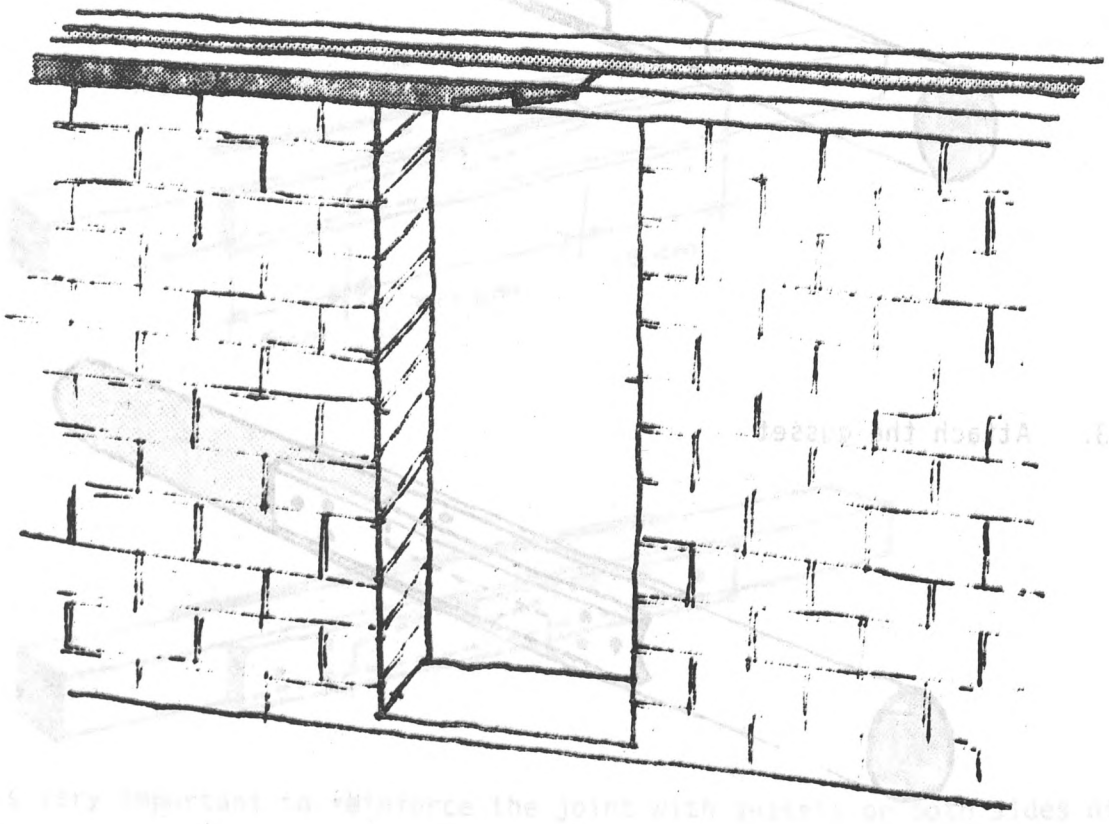
3. Attach the gusset



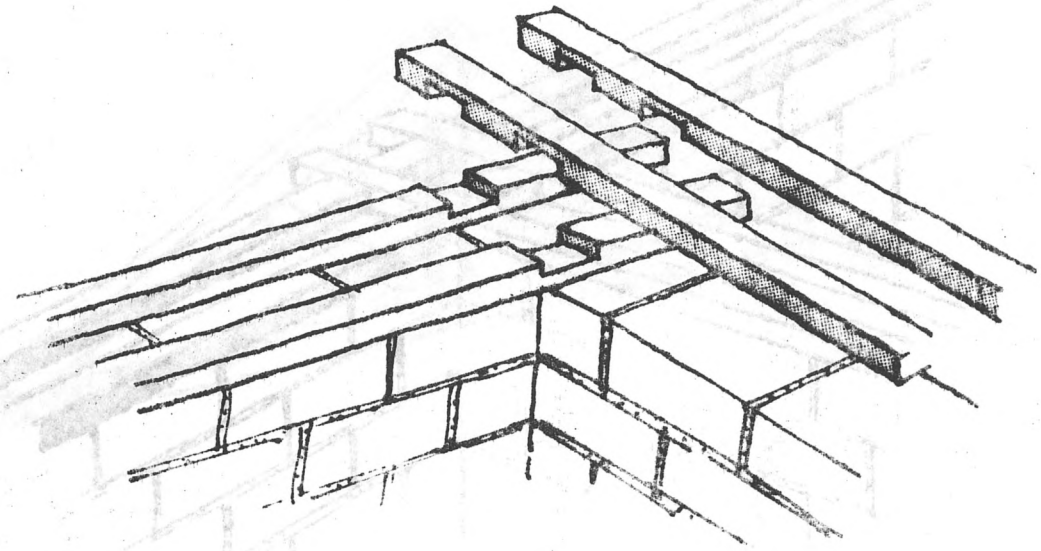
Use the "cadena" for the collar beam.

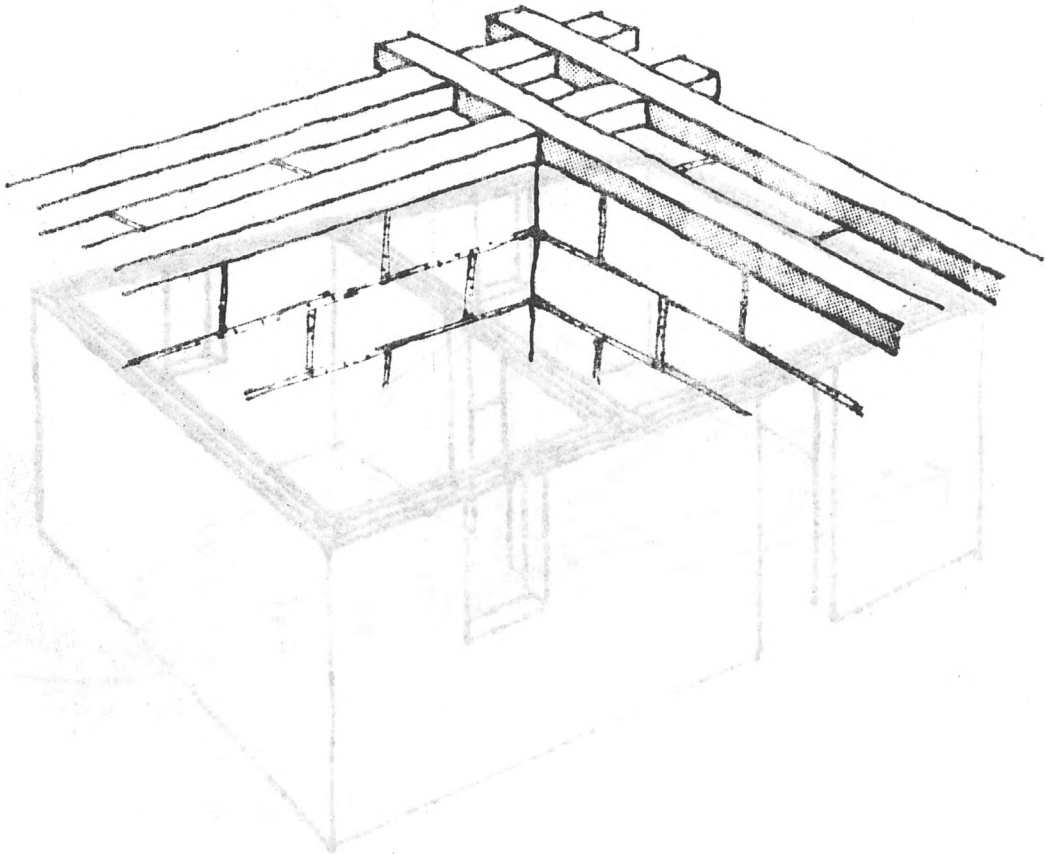


Do not put a joint over a door or window.

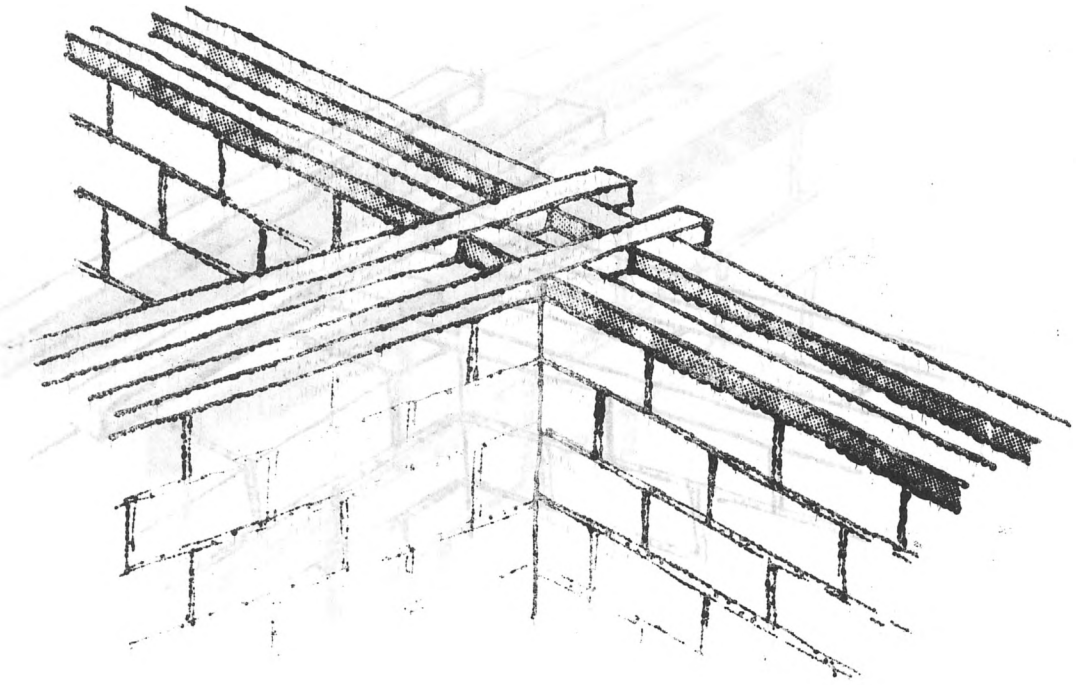


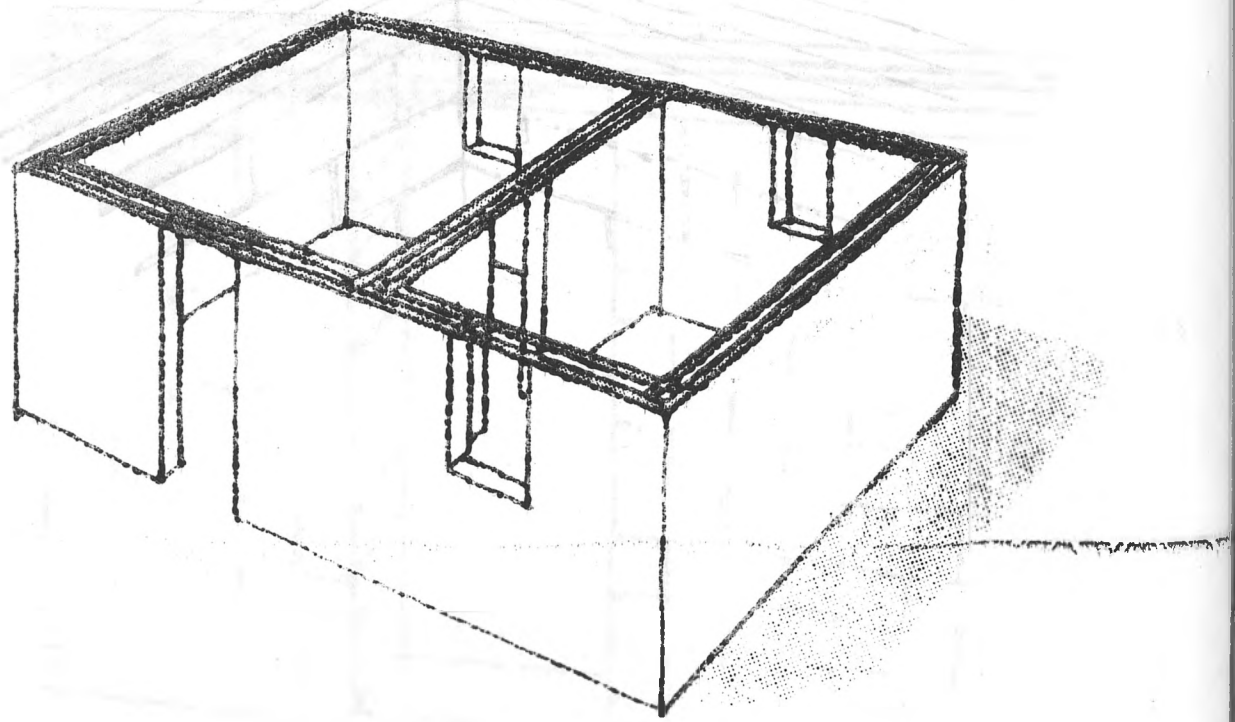
An "espiga" joint is best for the corners of the collar beam.





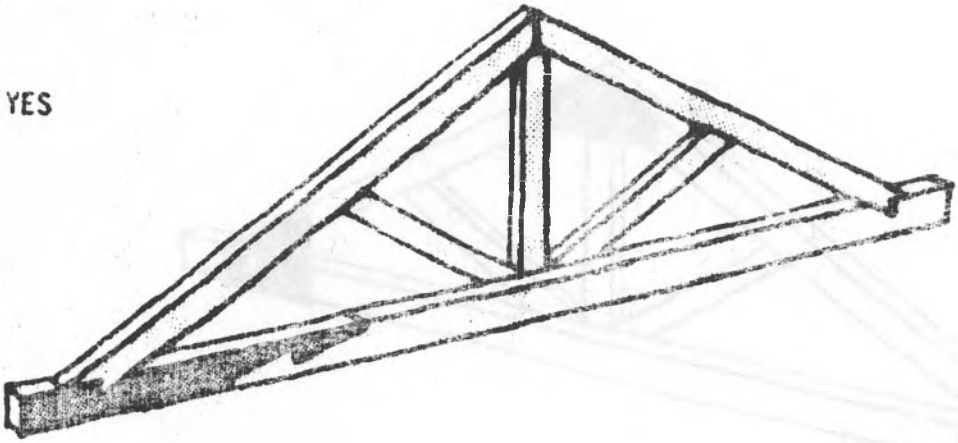
An "espiga" joint is best to unite the collar beam of an interior wall with the collar beam of an exterior wall.



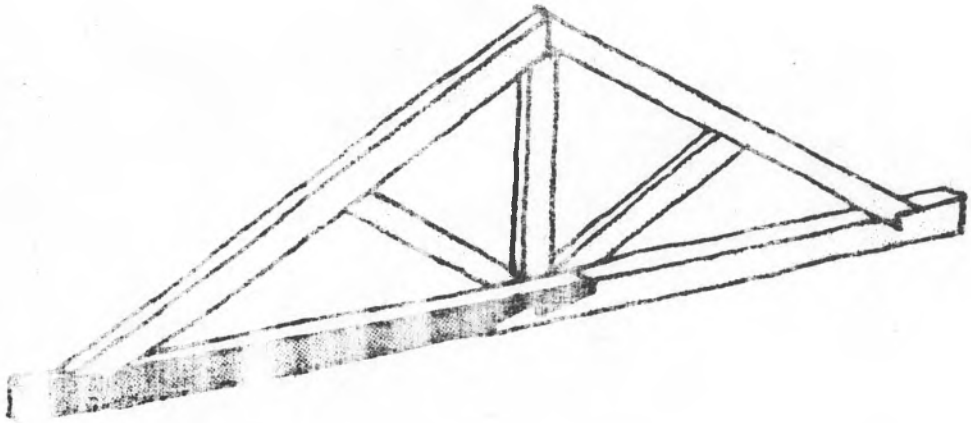


WHERE TO PLACE JOINTS IN THE ROOF TRUSS

YES



NO



WHERE TO PLACE GUSSETS IN THE ROOF TRUSS