IMPROVEMENT OF LOW-COST HOUSING IN TONGA TO WITHSTAND HURRICANES AND EARTHQUAKES

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1982

Study and recommendations prepared for
the Office of U.S. Foreign Disaster Assistance,
Agency for International Development
Washington, D.C. 20523

Contract No. PDC-0024-C-00-1113-00

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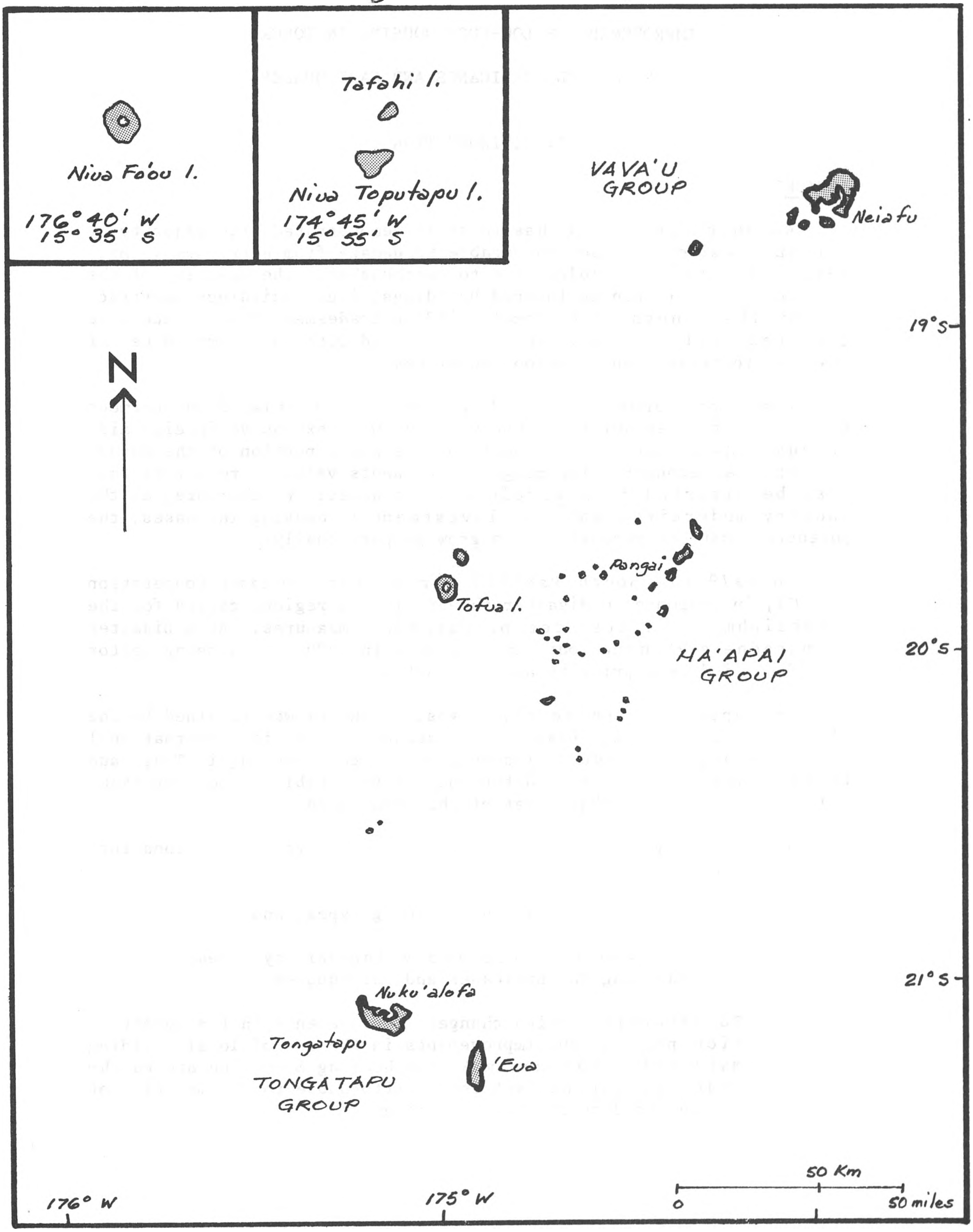


IMPROVEMENT OF LOW-COST HOUSING IN TONGA

TO WITHSTAND HURRICANES AND EARTHQUAKES

I. INTRODUCTION

BACKGROUND

As Hurricane Isaac has recently demonstrated, the majority of Tongans reside in houses vulnerable to damage from hurricanes. Many buildings are also vulnerable to earthquakes. The majority of the people reside in non-engineered buildings, i.e., buildings constructed by the owners or by local building tradesmen without extensive architectural or engineering input and with only limited use of disaster resistant construction techniques.

Isaac and other recent hurricanes have placed an enormous financial burden on the country. Even with extensive foreign aid, reconstruction costs will account for a sizable portion of the annual budget. A reconstruction program represents valuable resources that must be diverted from development schemes. Furthermore, as the country modernizes and the investment in housing increases, the potential costs of reconstruction grow proportionally.

In 1979 the South Pacific Bureau for Economic Cooperation (SPEC), in response to disaster threats in the region, called for the establishment of disaster preparedness measures. At a Disaster Preparedness Planning Conference in Suva in 1979, the housing sector was identified as a priority area for action.

In support of these objectives, INTERTECT was retained by the Office of U.S. Foreign Disaster Assistance, Agency for International Development, to conduct a survey of low-cost housing in Tonga and three other countries to determine its vulnerability to hurricanes and earthquakes. The objectives of the Tonga study were:

A. To survey the low-cost housing of Tonga and the construction techniques used in order to:

   1. Classify the various building types, and

   2. Analyze the relative vulnerability of each type of building to hurricanes and earthquakes.

B. To determine design changes, improvements in the construction process, and improvements in the use of local building materials that can make the housing more wind and earthquake resistant, yet remain affordable to the majority of people residing in these buildings.

C. To make recommendations for dissemination of information about construction methods to protect buildings, including:

1. Short-notice or emergency situations (including instructions that can be disseminated when a hurricane threatens, methods for improving safety, and techniques for reducing damage and strengthening buildings to better withstand hurricane and earthquake forces);

2. Self-help actions for upgrading existing buildings through low-cost modifications or retrofitting measures; and

3. Recommendations on how to influence the design and construction of new houses.

DEFINITION OF TERMS

The following are brief definitions of the terms used in this report:

A. Design Changes: the process of altering the design of a structure before it is erected to make it more disaster resistant.

B. Disaster Resistant Construction: a term used to denote the degree to which a structure can be made more resistant to (or safe from) certain natural phenomena. The term recognizes that no building can be considered totally safe, but that certain steps can be taken to improve performance or survivability.

C. Housing Education: instruction for homeowners or builders on how to build a safer or more disaster resistant house.

D. Housing Modification: changes in the configuration of an existing building to make it stronger. Modifications might include changing the pitch of the roof, adding a room, etc.

E. Non-Engineered Buildings: those structures built either by homeowners or by local building tradesmen such as carpenters and masons without formal architectural or engineering inputs into the design or construction process. For the purposes of this report, the term only considers those structures which could be considered formal houses; it does not include the temporary out-buildings often used by families as rooms for older boys or for storage of belongings.

F. Progressive Upgrading: systematic improvements to existing buildings to increase disaster resistance. Measures may include modifications and/or retrofitting.

G. Retrofitting: the process of installing additional supports or altering components of an existing building in order to make it more disaster resistant.

H. Risk: the relative degree of probability that a hazardous event will occur. An active fault zone, for example, would be an area of high risk.

I. Traditional Housing: indigenous modes and styles of housing using local traditions, skills and techniques. Traditional housing can be identified by a particular style or design of construction, by popular features, and/or by the building methods used.

J. Transitional Housing: transitional buildings are structures that use a combination of traditional and manufactured materials (e.g., houses with wood and mat walls and corrugated iron (C.I.) sheet roofs).

K. Vulnerability: a condition wherein human settlements or buildings are exposed to a disaster by virtue of their construction or proximity to hazardous terrain. Buildings are considered vulnerable if they cannot withstand the forces of high winds or earthquakes. Communities in unprotected, lowlying coastal areas exposed to hurricanes, or in seismic areas where a large proportion of the structures cannot withstand the forces of an earthquake, are considered "vulnerable communities".

II. RISK IN TONGA

HURRICANE RISK

Tonga is situated on the edge of one of the most active hurricane regions in the world. Within the last decade, two hurricanes have struck the island. The casualties and damage in each hurricane underscore the vulnerability of the population and show that a majority of housing cannot withstand the forces of high winds.

Hurricanes threaten housing in Tonga with:

--- Damage or collapse resulting from the forces of high winds;

--- Inundation from storm surges (popularly known as tidal waves) affecting lowlying coastal areas.

Figure 2 depicts the tracks of hurricanes that have struck Tonga in the last 30 years. Figure 3 depicts a cross-section of a typical hurricane, showing the sector of the storm system that produces the most damage. It can be seen from this drawing that the band of destruction can be fairly wide, often spanning a diameter of up to 100 miles. Because of the relatively small size of the island groups, as well as the number of small islands, no areas are completely safe from high winds.

High winds can cause extensive damage to any type of structure, but generally lightweight buildings, especially those made of traditional materials, are more susceptible to damage if basic hurricane resistant building features are not incorporated into their design and construction. Although older traditional structures were generally strong and fairly resistant, many traditional skills and design features have been lost over the years and more recent structures are more vulnerable. Because the majority of buildings outside the major cities are built with little engineering input, they often do not have adequate resistance to high winds.

EARTHQUAKE RISK

Tonga is situated near the northeastern edge of the Australian Plate, close to where it abuts the Pacific Plate (see Figure 4). It is the relative movement along this jointure or "fault" that causes the earthquakes which periodically affect the country.

Earthquakes threaten housing in Tonga in three ways:

--- Forces generated by ground-shaking;

FIGURE 2 Hurricane Tracks 1940 - 1982

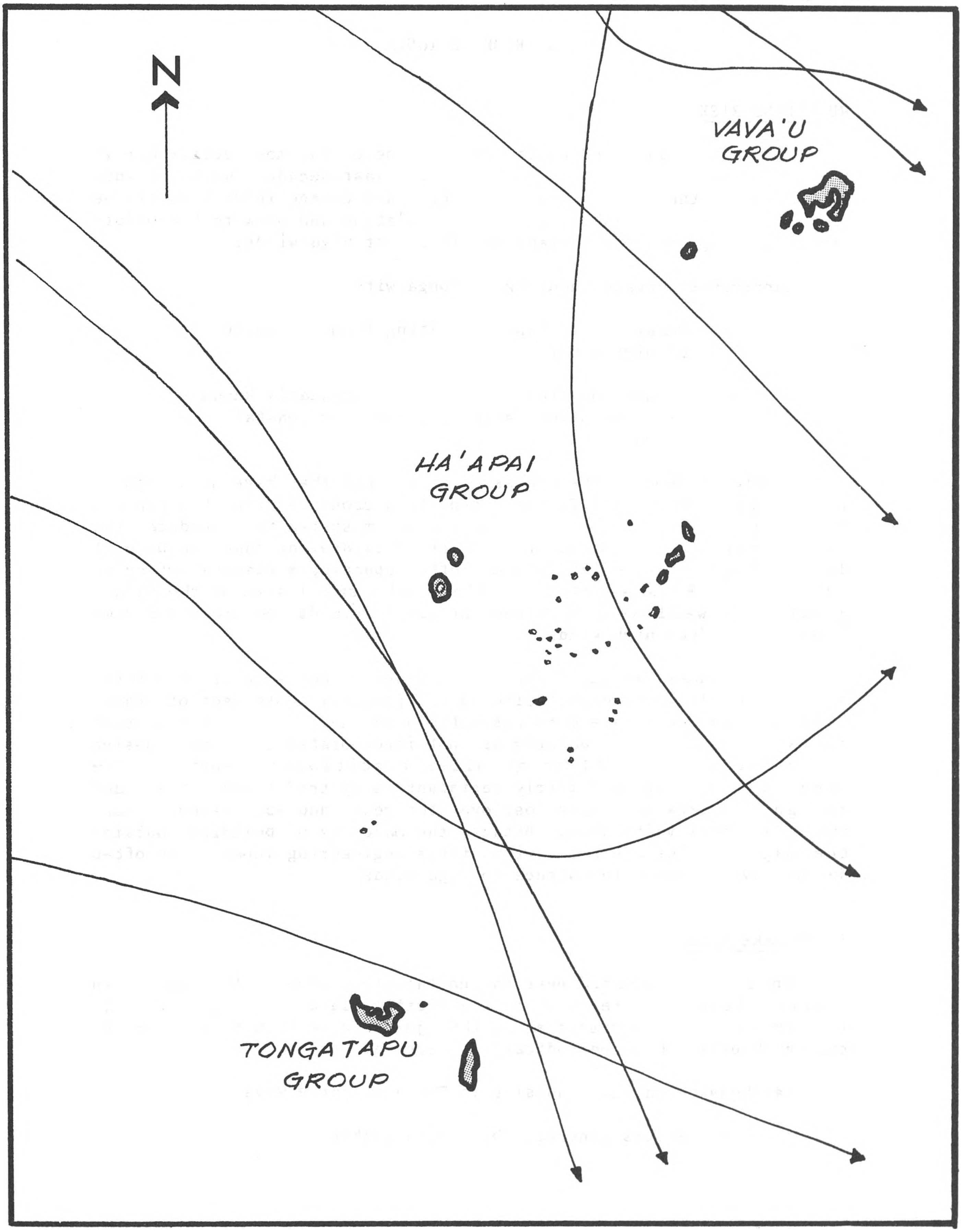
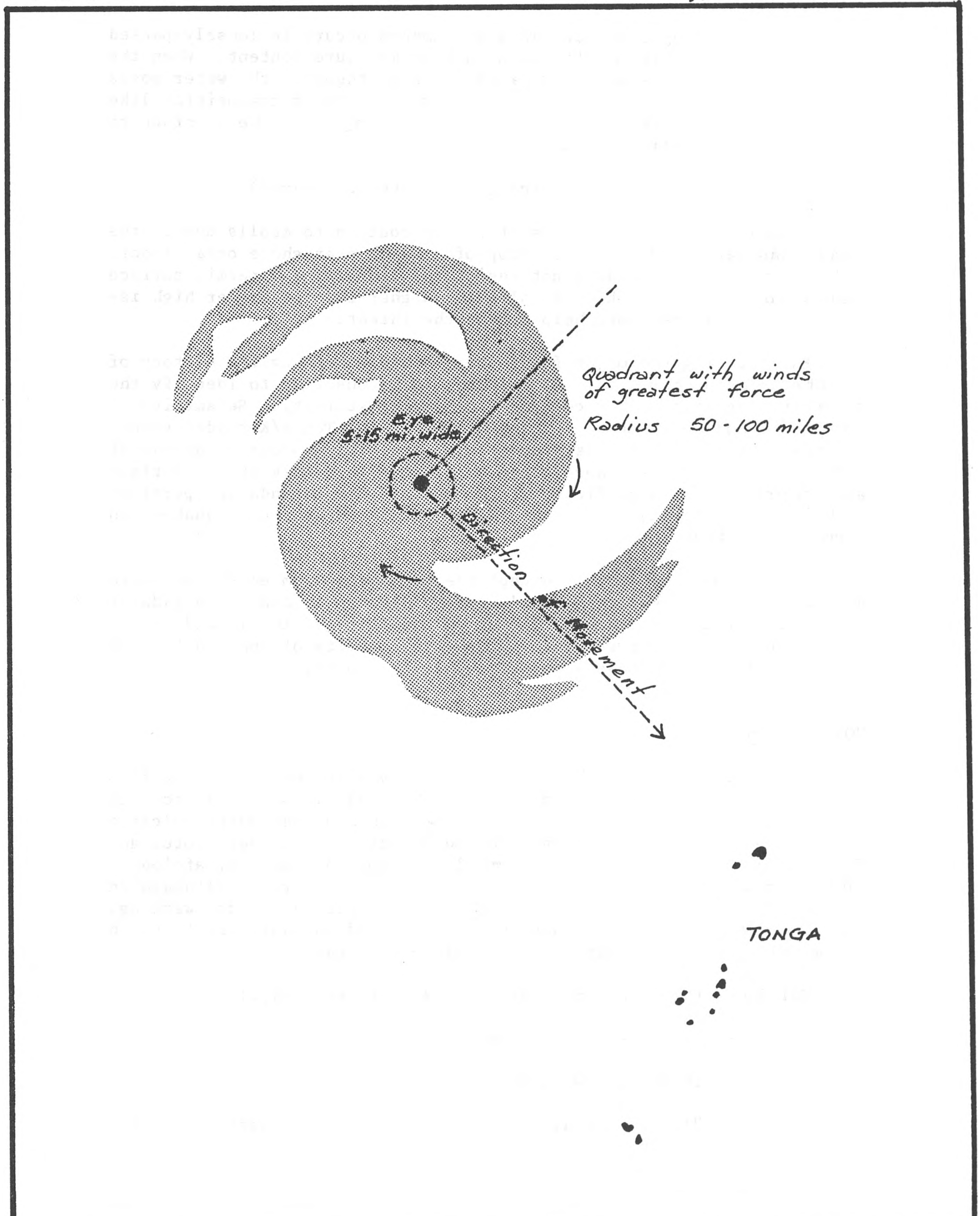


FIGURE 3 Cross Section of a Typical Hurricane



--- Liquefaction (This phenomenon occurs in loosely-packed sandy soils having a high moisture content. When the soils are vibrated by an earthquake, the water moves upward and turns the soils into a composition like quicksand, allowing buildings on the surface to partially sink or settle.); and

--- Tsunamis (seismically-generated sea waves).

Damage from tsunamis is of little concern to atolls due to the small land area and the steep drop-off of the near shore ocean floor. (The small land area does not resist the tsunamis and permit surface waves to build up.) Risk is slightly higher for the larger high islands, but offshore reefs help reduce the threat.

By locating the major fault systems and examining the history of earthquakes throughout the islands, it is possible to identify the relative potential for recurrence of seismic activity. Seismicity in Tonga is influenced by activity along the Tonga/Kermadec trench system. Most of the earthquakes in this region occur at depths of 100-150 kilometers; therefore they are felt strongly at the surface and represent a significant risk. Because the islands are parallel and immediately adjacent to the Tonga Trench, strong earthquakes can occur at any time on any of the islands.

The buildings most susceptible to damage from earthquakes are heavy buildings, especially multi-story structures and those made of concrete block or panels. The seismic history of the islands indicates that it is important to improve the quality of construction of large buildings and those made from concrete blocks.

VOLCANO RISK

Many of the islands were formed by volcanoes resulting from eruptions along the western ridge of the Tonga Trench. As recently as 1946, the island of Niuafo'ou was evacuated due to volcanic eruptions. Two of the islands formed by active volcanoes, Tofua and Niuafo'ou, are occupied by small settlements. Only Niuafo'ou is considered to have any significant degree of risk, although an increase in volcanism could occur with little advance warning. Fonualei and Late, two islands that experienced volcanic eruptions in the mid-1800s, are now dormant but could erupt again.

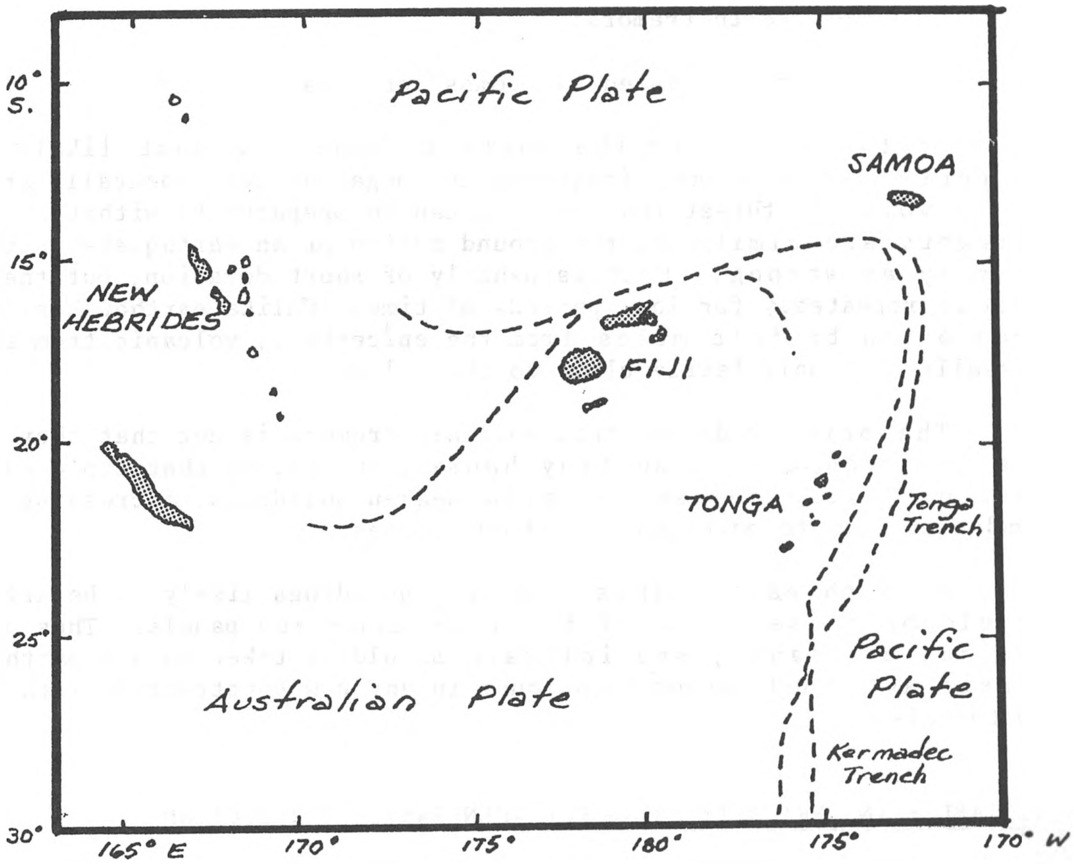
Volcanoes threaten human settlements in several ways:

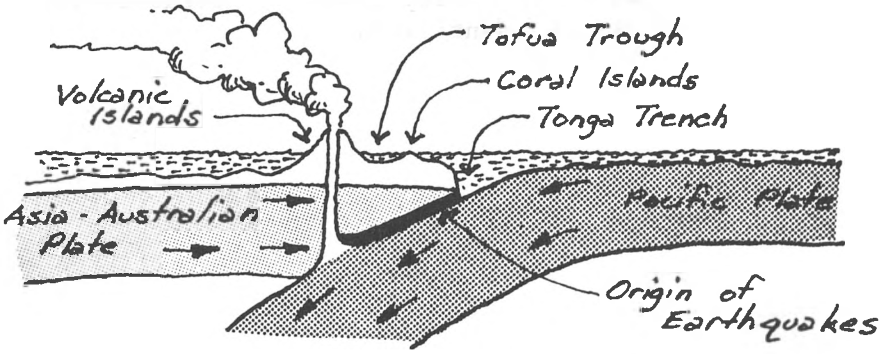
--- cataclysmic eruptions;

--- inundation with ash fallout;

--- "bomb" damage caused by boulders ejected from the volcano;

FIGURE 4 Tectonics of the S.W. Pacific





--- lava flows;

--- earth tremors;

--- fires caused by "bombs" or lava.

Of these threats the earth tremors are most likely to be experienced with any frequency in Tonga and coincidentally are the only volcanic threat that housing can be prepared to withstand. The tremors are similar to the ground motion of an earthquake, although rarely as strong. Each is usually of short duration, but they may occur repeatedly for long periods of time. Unlike earthquakes (which can often be felt miles from the epicenter), volcanic tremors are usually felt only fairly close to the volcano.

The primary danger from volcanic tremors is not that they would be so strong as to destroy houses, but rather that repeated low-strength ground-shaking could weaken buildings, increasing their vulnerability to earthquakes and hurricanes.

As with earthquakes, the only buildings likely to be affected would be those built of block or concrete panels. Thus on the volcanic islands, special care should be taken to use earthquake resistant construction techniques in any new construction with these materials.

ESTABLISHING PRIORITY AREAS FOR VULNERABILITY REDUCTION

As a general rule, comprehensive vulnerability reduction efforts should be initiated in areas where there are certain indicators that such efforts will succeed. Among the indicators are areas where new construction is occurring (such as towns), areas where agricultural activities are strong and where migration from rural to urban areas is minimal, and areas where a threat from a disaster is perceived as being a major problem to the majority of homeowners within the region. Thus by examining demographic trends and density, and areas of economic growth, priority areas for establishing vulnerability reduction efforts can be identified.

III. VULNERABILITY ANALYSIS OF TONGAN LOW-COST HOUSES

The purpose of this chapter is to identify the most common types of low-cost houses, to identify the structural problems of each type, and to determine their relative vulnerability to both high winds and earthquakes. Options for improving the structural performance of each building type are then considered.

DETERMINANTS OF VULNERABILITY

The extent to which a house is vulnerable to a disaster is determined by four factors: design and configuration of the house; quality of workmanship; strength of the materials used; and relative safety of the site. In general, buildings made of lightweight materials are more susceptible to damage from high winds, while buildings made of heavier materials (such as block or concrete panels) are more susceptible to damage from earthquakes.

Vulnerability to hurricanes is determined by:

--- configuration of the building;

--- configuration of the roof;

--- angle of the roof (a 30-45^{o} angle is best);

--- how well the building is tied together;

--- how securely the roof is tied to the walls;

--- how well the building is anchored to the ground.

Thus the buildings most vulnerable to hurricanes 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.

Roof configuration and construction are very important considerations for all types of housing. If the roof is not adequately attached and braced, and has a large overhanging eave, it is potentially the weakest part of the house.

Vulnerability of housing to earthquakes is determined by many of these same factors, plus several others. In addition to configuration and structural integrity, other determinants are:

--- Site (should be flat with stable soils)

--- Foundation (should be strong and level)

--- Balance (parallel walls should be of equal size and weight)

--- Center of Gravity (walls should be low; roof should be lightweight)

--- Reinforcement in the Walls (adequate vertical, horizontal and diagonal reinforcing should be placed in each wall)

In areas of seismic activity, the most vulnerable houses are the unreinforced or poorly-constructed concrete block and concrete panel buildings. Theoretically, these types of housing should be fairly easy to reinforce to a basic standard of earthquake resistance, and some block houses do use adequate iron reinforcement. However, the quality of the blocks in many areas and the workmanship and detailing are very poor; thus some buildings may be particularly vulnerable.

Again, it is important to remember that "risk" means the chance that some type of event like a hurricane might strike an area; "vulnerability" refers to the possibility of a building or settlement being damaged by that event. Thus, if a strong building is sited in a high risk area, it may not be vulnerable.

COMMON BUILDING FEATURES

A. Features and Practices Which Reduce Vulnerability

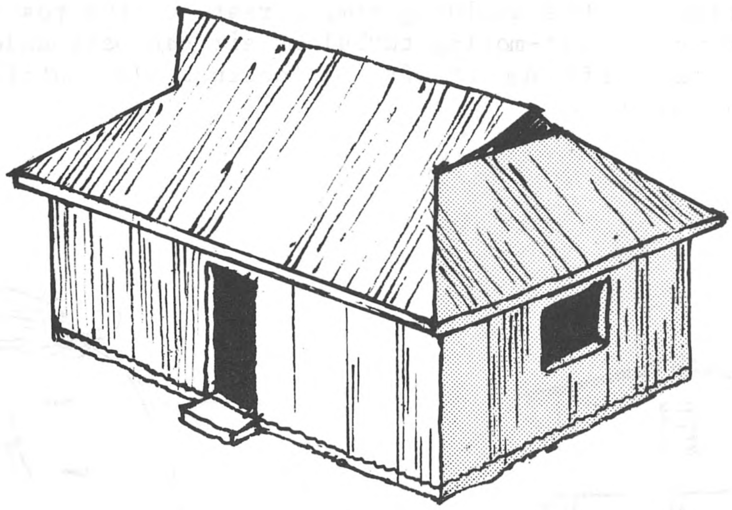
1. Hipped Roofs: Many buildings, especially traditional fales and older wood frame houses, use "hipped" roofs which offer excellent protection in high winds. Continued use of hipped roof configurations should be encouraged.

2. Hurricane Straps: In many buildings, the practice of using metal straps and other devices to fasten the roof trusses to the building is fairly common. In recent years this practice seems to have gained more acceptance, and planners should encourage increased use of these measures.

3. Small Eaves: The roofs of many fales project only a few inches over the sides of the walls. This reduces uplift under the eaves and damage to the roof. Where shading is required for windows, breakaway awnings can be used, as is the practice in many of the older wooden homes.

4. Vented Roofs: Vented roofs, such as the one illustrated on the following page, provide excellent hurricane resis-

tance as long as the vents are sealed during high winds.



5. Low Center of Gravity: Many early buildings were built so that the weight of the structure was distributed with heavier construction materials at the base and progressively lighter materials as the height increased. In part this was due to architectural and engineering techniques of that period. The practice helps protect against earthquakes and hurricanes, and should be encouraged.

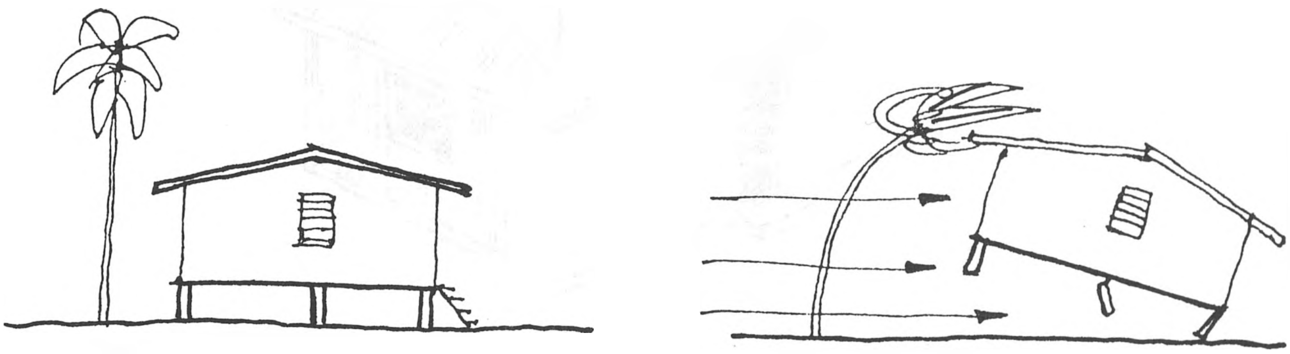
B. Features and Practices Increasing Vulnerability

1. Flat or Slightly Pitched Roofs: In recent years flat or "shed" roofs have become popular. This configuration is especially vulnerable to damage in hurricanes. The low pitch increases suction and uplifting forces, and the normally large overhang associated with this type of roof lends itself to uplifting at the edges.

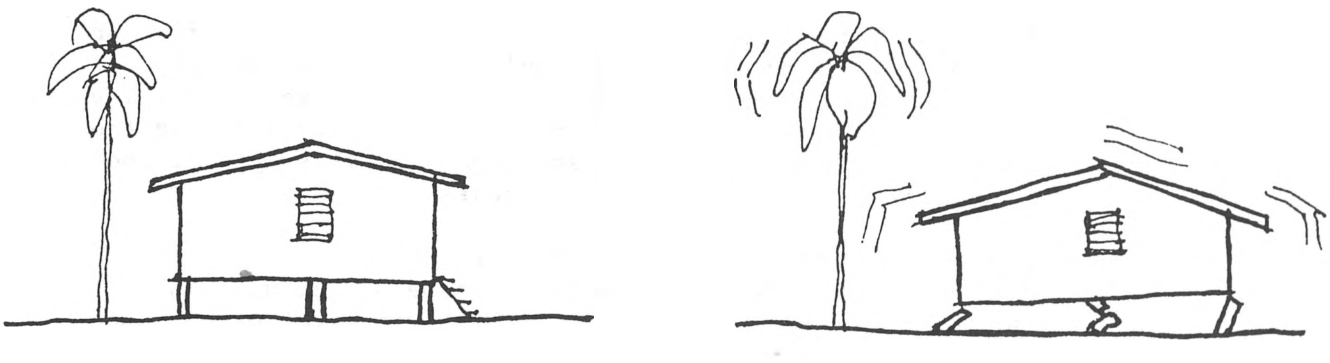
2. Louvered Windows: Louvered windows, particularly those made of glass or flimsy metal, can be dangerous in hurricanes. Vibrations caused by high winds can often cause metal fatigue, destroying the louvers and permitting excessive amounts of wind to enter the house. Glass louvers can be shattered by flying debris, injuring persons inside the house. If louvers are used, storm shutters should be added.

3. Verandas: Verandas or open porches are a popular feature on many houses. Many of the designs used for verandas contribute to wind damage, particularly if the veranda is formed by extending the main portion of the roof over the edge of the house. Breakaway verandas, such as those illustrated in other parts of this report, should be used.

4. <u>Concrete Piers</u>: Many of the smaller wood frame buildings are placed on short concrete posts. In some cases, there is some provision for anchoring the frame to the pier, but usually the building simply rests on the posts. In hurricanes, fast-moving turbulent air can pass under the structure, lifting it off its footings and contributing to its collapse.



In earthquakes, the ground motion is likely to shake the footings underneath the building, thereby collapsing the walls.

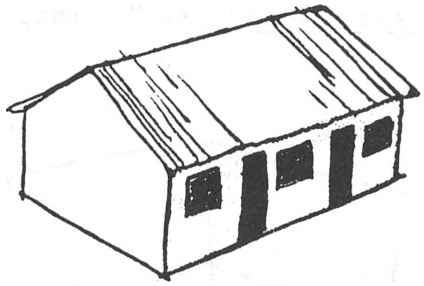


Wood frame buildings need strong wall-to-ground connections; concrete buildings need a solid rock and/or poured concrete foundation.

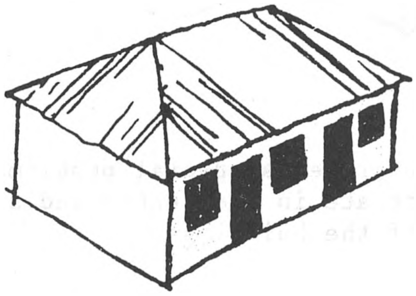
COMMON PROBLEMS

There are a number of problems common to most types of housing in Tonga. The following section describes some of the more popular styles and details that have been identified as being dangerous in either hurricanes or earthquakes.

A. Roof Configuration: Many buildings in Tonga utilize a gable roof such as the one illustrated in the figure below.



For both hurricane and earthquake resistance, a hipped roof such as that illustrated below is preferred.



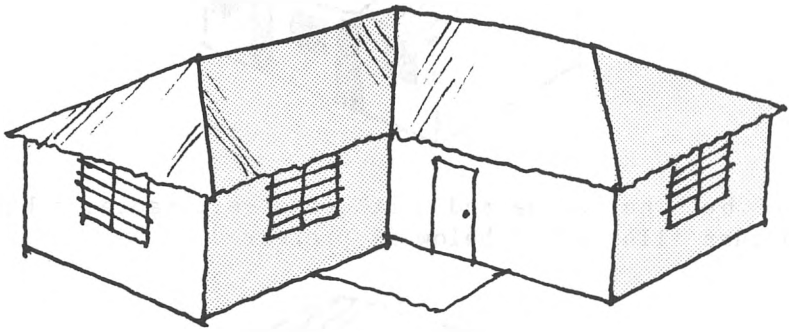
A gable roof may be used, however, if the angle of inclination of the roof is approximately 30-40°, and if the roof trusses are adequately braced so that they do not collapse when forces are applied along the longitudinal axis of the house,

NO YES

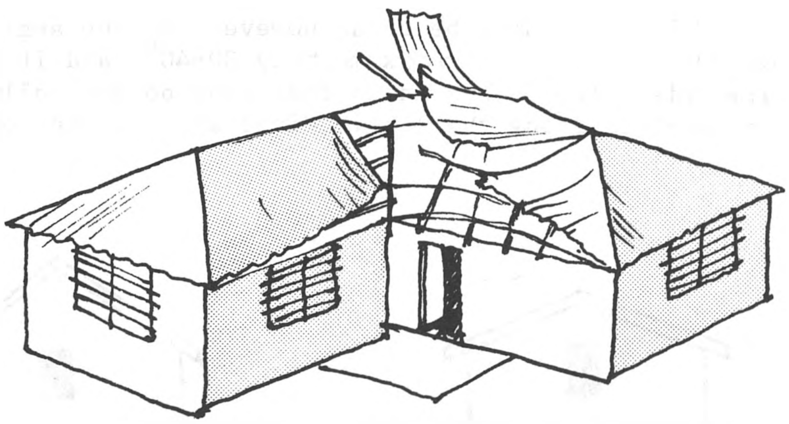
and provided that the gable is sufficiently reinforced so that it does not fail and collapse when pressures are exerted from either an earthquake or a hurricane.

The roofs of fales are well-configured and meet the requirements for wind resistance. However, in the other types of housing the roofs are often too flat. The lack of roof truss reinforcing and poorly-built gables are common to all types of transitional buildings.

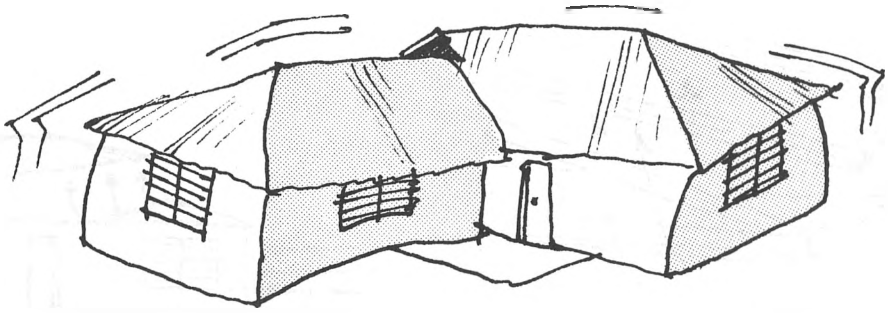
B. <u>"L"-Shaped Configurations</u>: An "L"-shaped building is illustrated below.



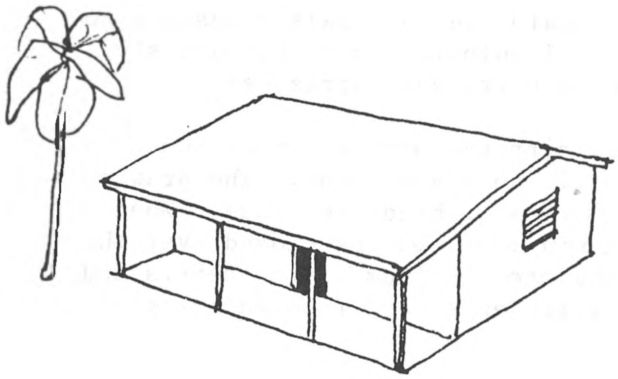
This configuration presents special problems in hurricanes when high winds concentrate in the center and are deflected upward, lifting the roofs off the buildings.

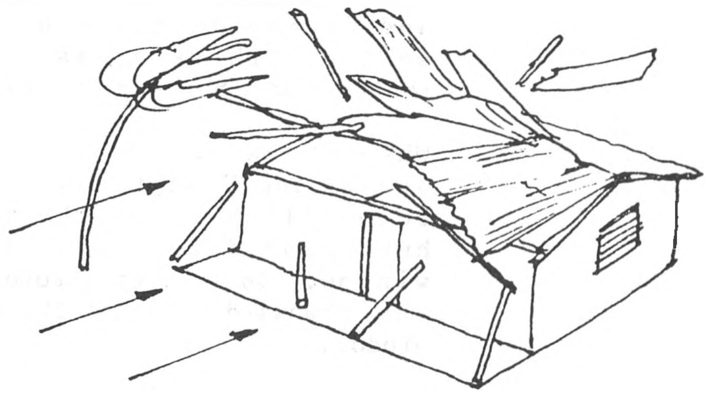


In earthquakes, this configuration is also dangerous, especially if the house is made of heavy material such as concrete block. The parallel walls of the house are of unequal weight and length and, in an earthquake, the house would twist on its foundation and collapse inward.

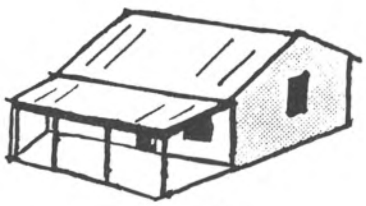


C. <u>Verandas</u>: The manner in which a veranda is constructed affects the vulnerability of a house. If the veranda is attached to the roof structure and traps wind underneath, the entire roof can be lifted off the house. A popular veranda and its pattern of failure are illustrated below.

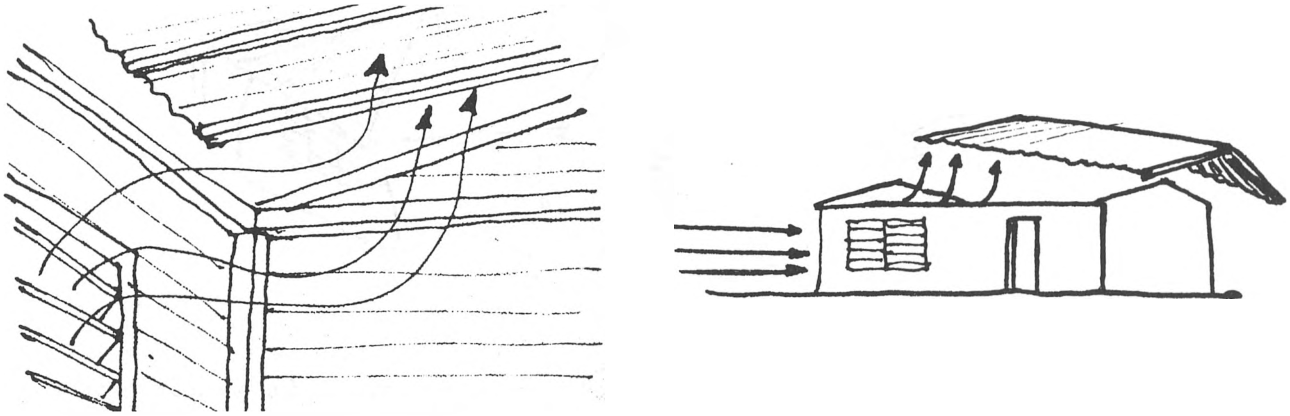




If this configuration is to be used, the connections between the veranda and walls and roof structure must be designed in such a way that the veranda can break away from the main structure of the house without severely damaging the rest of the house.

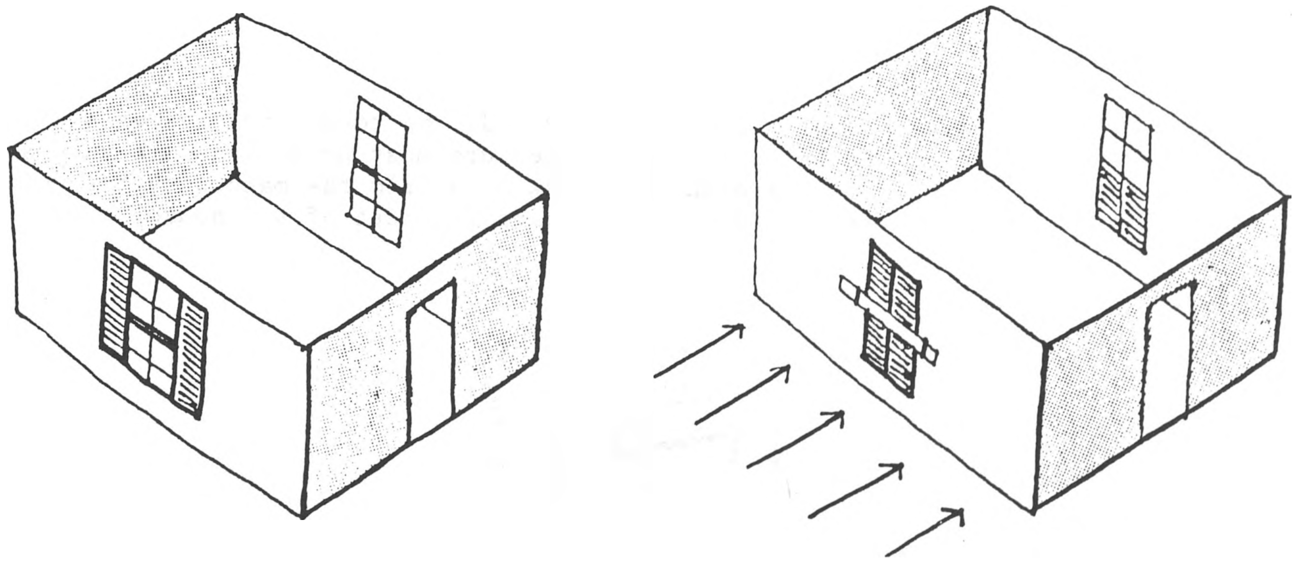


D. <u>Louvers</u>: Unless louvers are completely sealed off during a hurricane, excessive wind can enter the building, increasing the upward pressures on the roof.

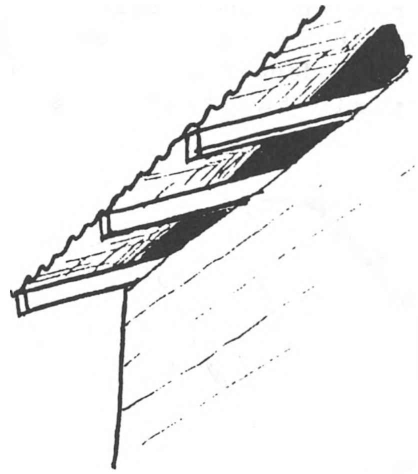


In theory, it should be possible to board up these areas before a hurricane, especially if adequate warning is given. In practice, however, when a warning is received, wood becomes scarce and it may be difficult to obtain the materials necessary to seal off these areas. The ideal solution is to install storm shutters which can be closed when a hurricane approaches.

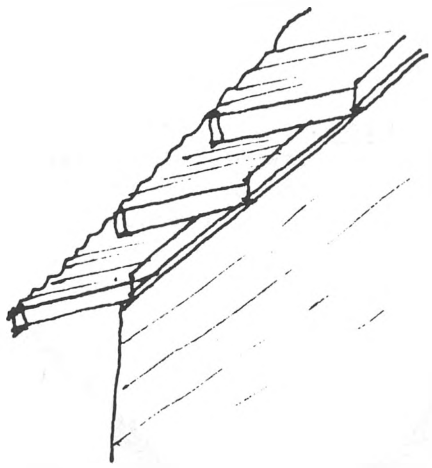
When placed over a relatively airtight window, storm shutters are an ideal adaptation to a hurricane environment. The drawing below illustrates the principles behind their use. When a hurricane threatens, the storm shutter is closed over the window. The shutter protects the opening from flying debris and the downward angle of the panels prevents rain from entering the window.



E. <u>Open Spaces</u>: Many houses in the rural areas leave open space between the roof and walls. This allows air to enter the house for cooling purposes. But during high winds this space permits excessive amounts of wind to enter the house and increases the outward pressure on the walls and roof.



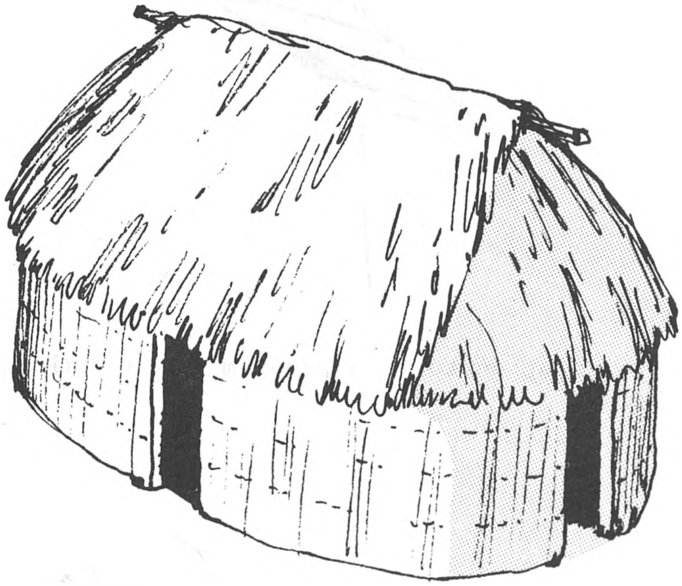
The best solution to this problem is to seal the eave as illustrated below.



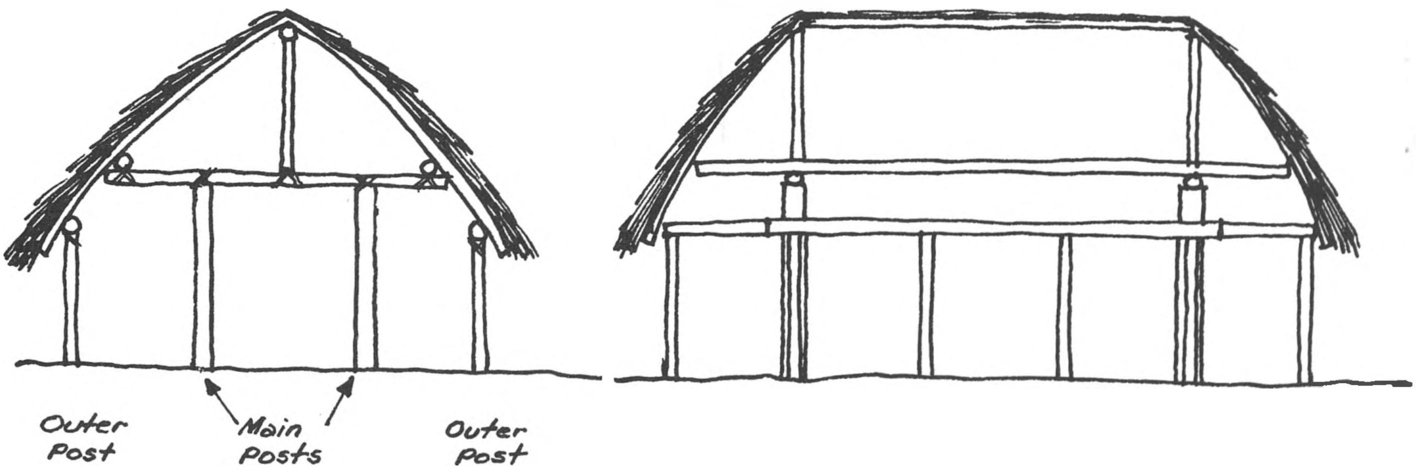
VULNERABILITY ANALYSIS OF THE BASIC CONSTRUCTION TYPES

A. Traditional Fales

Few traditional Tongan houses, or fales, are still found except on the more remote outer islands. It is unfortunate that the architectural style has not been retained, for the design is particularly well-adapted to the Tongan climate and environment, and when properly built it is a strong, hurricane resistant design.

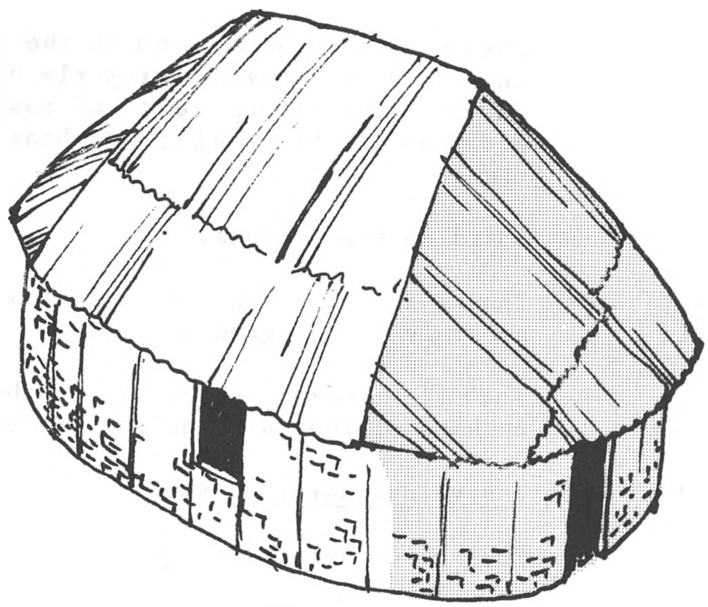


1. Construction: In traditional fales, four strong wood corner posts are set in the ground and a wooden roof frame is erected on top of the posts, extending beyond the center posts. Smaller wall posts are attached to create the main building frame.



Mats made of woven baamboo or reeds are attached between the corner posts to make the walls. These are often supported by small vertical posts which help to reinforce the walls in the center. Traditionally, the house is bound together with ropes made from coconut fiber or other natural materials, but in recent years construction wire has been used. In many of the newer fales, nails have replaced the binding.

2. Roof: Fales normally have a thatched roof made from pandanus (or, in a few cases, palm leaves). Almost all roofs are high and use a unique (4-sided) configuration with rounded ends. In recent years, many thatched roofs have been replaced by corrugated iron (C.I.) sheets.



3. Size: Fales average about 25 x 60 feet.

4. Vulnerability: Many of the older fales are quite strong, especially those that follow traditional construction methods and bind the buildings together with rope or wire. The configuration of fales is strong, and the configuration and pitch of the roof are excellent. The center posts are normally large and buried sufficiently to resist uplift; and the outer wall posts tend to anchor the buildings at the walls.

   The newer fales that use nails are very vulnerable to hurricanes because nails have insufficient friction and strength to resist the pressures on the joints caused by hurricanes.

5. Other Weak Points: The weak points of the fales are the connections between the roof and center posts, the roof and the outer posts, and deteriorated wall posts. Other weak points which allow excessive amounts of air to enter a building during a storm are the doors and windows.

6. Modifications for Wind Resistance: In order to improve the wind resistance of fales, the following actions are necessary:

   a. Emergency measures

   --- The roof-to-wall connections should be strengthened by using metal straps or wire to help bind the roof to the walls, especially at the corner posts.

   --- Check all connections in the roof structure to ensure that they are properly bound. Next place additional heavy vertical posts in the central portion of the walls and bind them to the roof frame.

   --- Board up the windows.

   --- Throw ropes or nets over the roof and anchor securely to the ground.

   --- Install cross-braces of wire between the center columns of the building and the outer wall posts.

   b. Progressive upgrading measures

   --- Replace corner posts that are rotten.

   --- Use wood treatment for all parts of the house that are placed on or in the ground.

   --- The primary columns (center posts and outer columns) should be buried a minimum of 36 inches and should use some form of anchoring device.

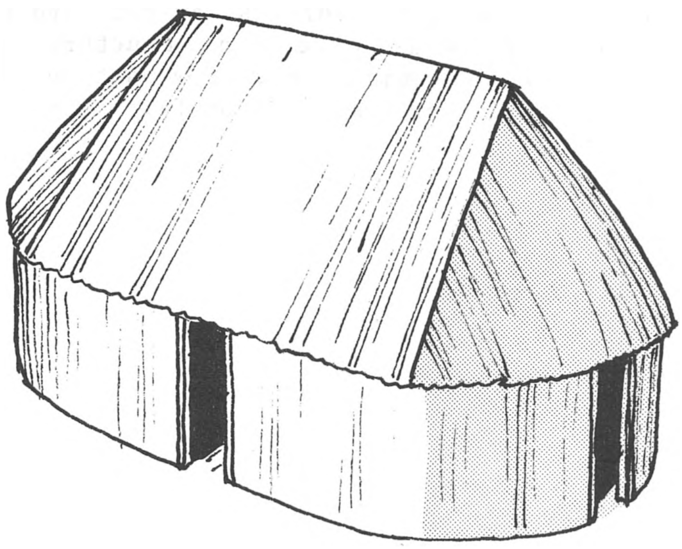
The hurricane resistance of fales, if properly built and reinforced, is moderate. Structural performance can be improved although, due to the type of construction, the building cannot be made airtight or sufficiently strong to withstand extremely high winds (over 100 mph) and structural damage can still be expected. If all the basic rules are followed, however, a substantial improvement in performance can be attained.

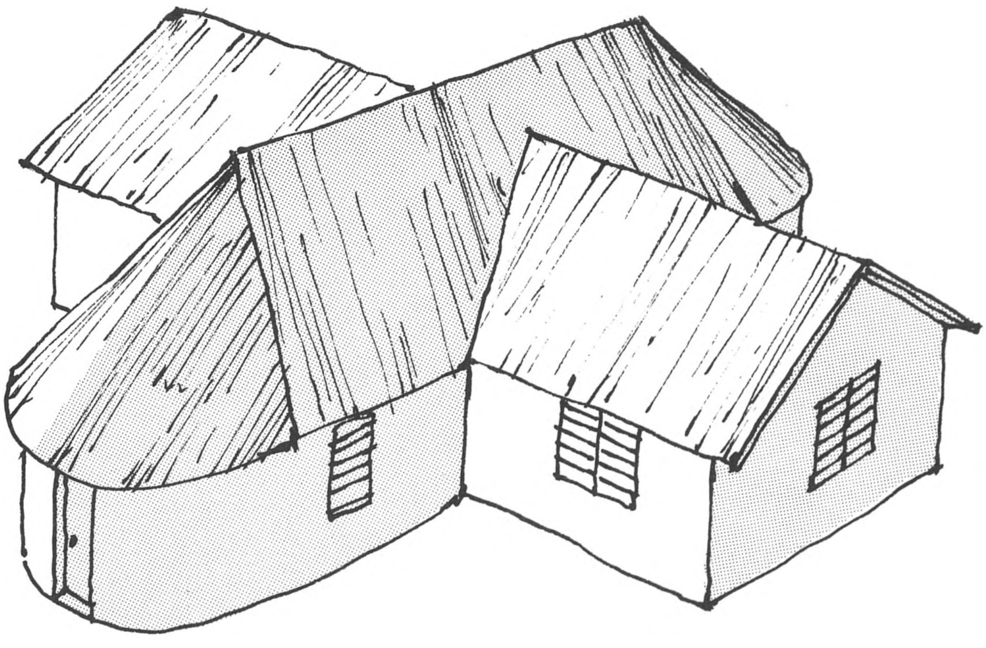
Even though extensive structural damage may result from hurricanes, the potential of serious injury resulting from collapse of these buildings is relatively minor. They are lightweight structures and, because they are woven together, components will not come flying off to cause major harm to occupants.

7. Modifications for Earthquake Resistance: In terms of vulnerability to earthquakes, fales are relatively safe. The principal problem is the central columns. In a strong-motion earthquake, the columns may not have enough vertical resistance to stabilize the structure and collapse may result. By following the recommendations outlined above, the earthquake resistance of fales can be substantially increased.

B. <u>Modern Fales (Wood Frame with C.I. Sheet Walls)</u>

Fales with C.I. sheet walls were once a popular transitional building, although only a few are still built each year. Several have been expanded in an interesting variation on the basic style, as shown below.





1. Construction: The frame for a modern fale is the same as for a traditional building. The sides are made of C.I. (corrugated iron) sheets instead of traditional mats.

2. Roof: The roof is also covered with C.I. sheets and the traditional configuration is maintained.

3. Size: Sizes average 20 x 50 feet.

4. Vulnerability: The most common damage caused by high winds is loss of C.I. sheets. In houses with louvered windows, damage may be caused by differential pressure pushing out on the walls until the C.I. sheets separate from the posts.

   Most modern fales are anchored to the ground by large center and wall posts. They provide enough strength to hold the buildings down in high winds.

5. Other Weak Points: Typical weak points are the connections between roof sheeting and roof trusses, connections between roof trusses and walls, and connections between C.I. sheets and wall posts.

6. Modifications for Wind Resistance: The following actions are necessary in order to improve structural performance in high winds:

   a. Emergency measures

      --- Use more nails to secure the C.I. sheets to the roof frame and wall truss.

      --- Use metal straps to secure roof trusses to walls.

      --- Seal the eaves of the house to prevent wind from entering under the overhang.

      --- Board up windows during periods of high wind.

   b. Progressive upgrading measures

      --- Place diagonal braces at the corner of the frame to hold the wall posts together.

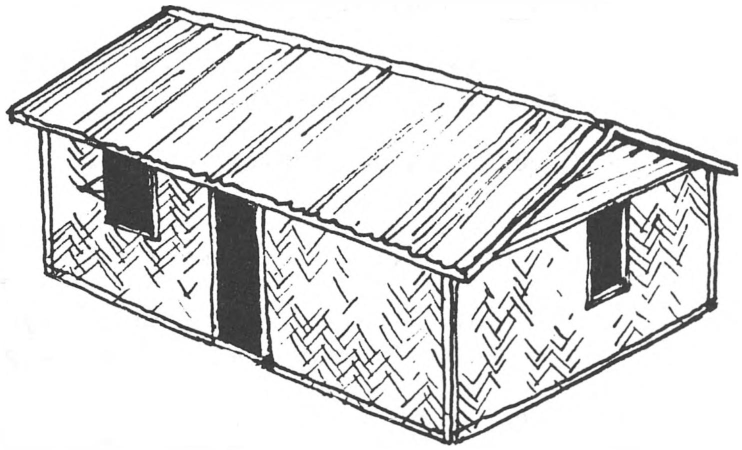
      --- Anchor the structure securely by placing anchoring devices on all outer wall columns.

   If these recommendations are carried out, the wind resistance of this type of structure will be substantially increased. If properly built, a modern fale will provide moderate safety in hurricanes.

7. Modifications for Earthquake Resistance: The earthquake resistance of metal fales is very good; by following the recommendations above, the margin of safety will be increased. The only major type of damage that should occur in an earthquake is collapse of the structure at the base due to deterioration of wood columns. Diagonal bracing and treatment of all wood in or on the ground would make earthquake damage almost negligible.

C. Transitional Buildings

1. Construction: Rectangular structures with walls made of wood posts covered with traditional mats are among the most popular building types found in rural Tongan villages. The houses offer the advantages of ease in construction and suitability to the climate. If properly maintained, they will last for several years and can be upgraded by replacing the mats with boards.



2. Roof: Corrugated iron sheets are used most often, but some roofs are made of pandanus thatch. The most popular configuration is a two-sided (gable) roof.

3. Size: Sizes vary from 12 x 15 feet to 15 x 30 feet.

4. Vulnerability: The most common damages caused by high winds are roof separation and destruction of the walls. In houses with mat windows, excessive wind may enter the building, pushing out on the opposite walls until portions rip away.

   The houses are anchored to the ground by the corner posts of the frame. If the posts are not buried fairly deep, the house will be insufficiently anchored, and in hurricanes the posts will be lifted out of the ground.

5. Modifications for Wind Resistance: The following actions are necessary in order to improve the structural performance of transitional houses in high winds:

   a. Emergency measures

      --- If C.I. sheets are used, use more nails to secure the sheets to the roof frame or truss.

--- Use metal straps to secure the roof trusses to the walls.

--- Put diagonal braces in the roof frame at the corners.

--- Board up windows during periods of high wind.

--- Place wire cross-braces between the corner posts.

b. Progressive upgrading measures

--- Change gabled roofs to a hipped roof configuration when rethatching.

--- Increase the pitch of the roof.

--- Place diagonal braces on top of the frame at each corner to tie the walls together.

--- Anchor the structure securely by replacing small corner posts with longer, heavier posts.

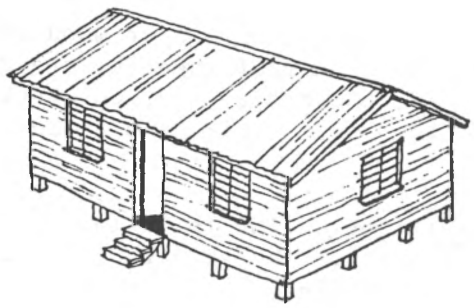
If these recommendations are carried out, the wind resistance will still be fairly poor. This type of structure can only provide moderate safety in hurricanes. However, collapse is not likely to cause serious injury.

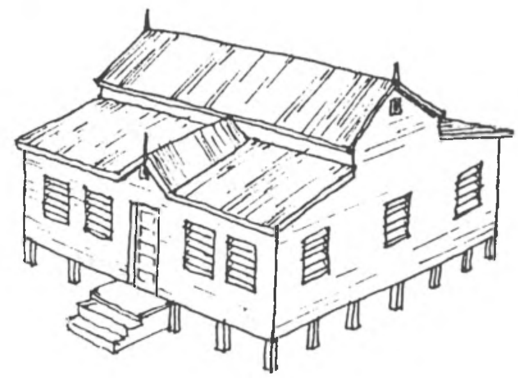
6. Modifications for Earthquake Resistance: The earthquake resistance of transitional houses is very good and, by following the recommendations above, the margin of safety will be increased. The only major type of damage that should occur in an earthquake would be collapse of the structure at the base due to insufficient vertical resistance of the corner posts.

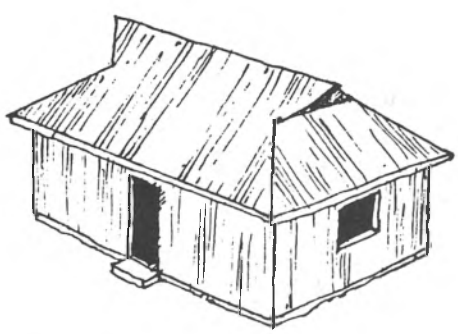
D. Wood Frame Construction

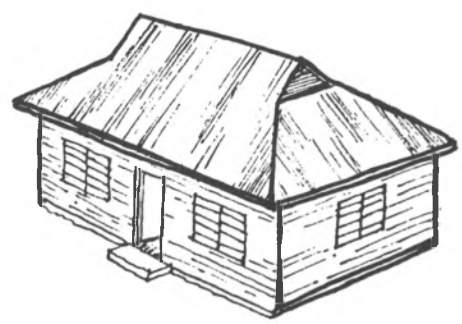
Wood frame houses are popular in Tonga. Most people consider these buildings to be "modern" even though several designs are over 25 years old. Popularity may increase if economically attractive timber from Fiji becomes more available in the mid-1980's. The houses offer the advantages of ease in building additions and suitability to the climate. If properly maintained, they will last for many years.

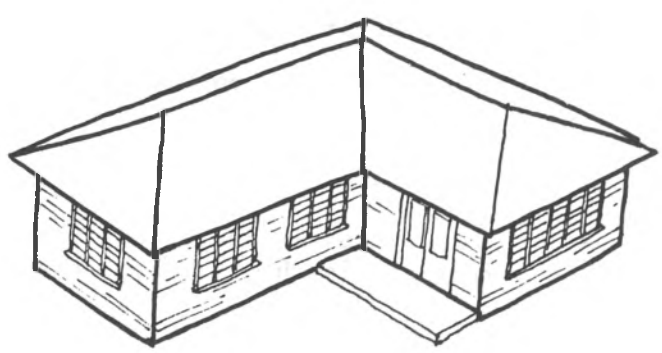
1. Construction: There are many variations of wood frame houses, ranging from small one-room buildings on concrete piers to wood panel buildings anchored to concrete foundations. Some of the more popular designs are shown below.











2. <u>Roof</u>: The preferred roof covering for wooden houses is C.I. sheets. The majority of roofs are gabled, although many use a hipped configuration.

3. <u>Size</u>: Sizes vary from 12 x 15 feet to 20 x 50 feet.

4. <u>Vulnerability</u>: The most common damage caused by high winds is roof separation. In houses with louvered windows, damage may be caused by differential pressure pushing out on the walls until boards separate from the columns.

   Many wood frame houses rest on short concrete posts or piers or are anchored to the ground only by the corner posts of the frame. This is insufficient anchorage for hurricanes, and the houses will be lifted off the ground and toppled over.

5. <u>Other Weak Points</u>: Typical weak points of wood frame houses are the connections between roof sheeting and roof trusses (most nails are too short), connections between roof trusses and walls, and connections between the building and the ground.

6. <u>Modifications for Wind Resistance</u>: The following actions are necessary in order to improve the structural performance of wood frame houses in high winds:

   a. <u>Emergency measures</u>

      --- Use more, and longer, nails to secure the roofing sheets to the roof frame or truss.

      --- Seal the area beneath houses on piers with rocks and mud to prevent uplift.

      --- Use metal straps to secure the roof trusses to the walls.

      --- Seal the eaves of the house to prevent wind from entering under the overhang.

      --- Board up windows during periods of high wind.

   b. <u>Progressive upgrading measures</u>

      --- Change gabled roofs to a hipped roof configuration.

      --- Increase the pitch of the roof, if necessary.

      --- Place diagonal braces on top of the frame at each corner to tie the walls together.

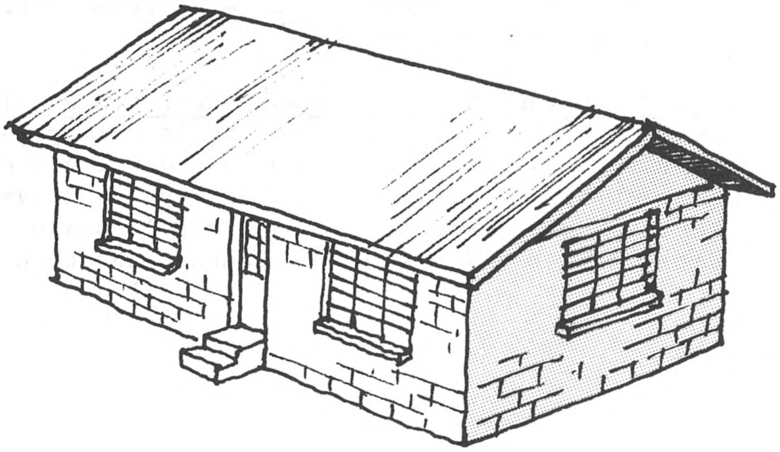
--- Anchor the structure securely. If piers are used, types with anchoring devices should be installed. If wood panels are bolted to the foundations, steel washers should be placed between the nut and the wood frame.

If these recommendations are carried out, the wind resistance for this type of structure will be substantially increased. If properly built, wood frame buildings provide moderate safety in hurricanes.

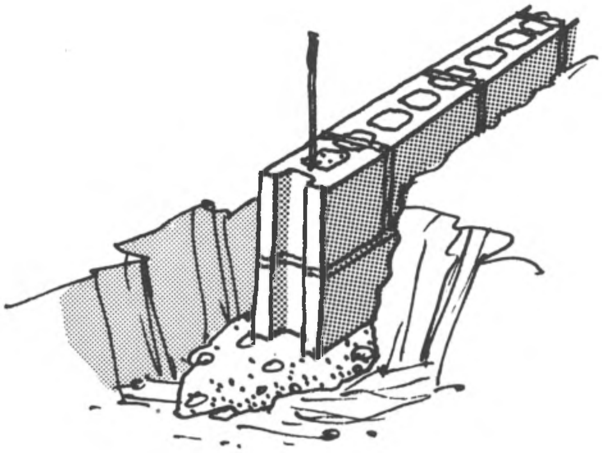
7. Modifications for Earthquake Resistance: The earthquake resistance of wood frame housing is very good and, by following the recommendations above, the margin of safety will be increased. The only major type of damage that should occur in an earthquake would be collapse of structures on piers due to failure of the connections to hold the building.

E. Concrete Block Construction

If properly built, a concrete block house can withstand the forces of both earthquakes and windstorms and is a safe form of construction. If improperly built and reinforced, this type of construction is the most dangerous. The most popular block house is illustrated below.



1. Construction: The strength of a block house depends on the amount of reinforcement at the corners, the amount of vertical and horizontal reinforcing in the walls, the strength of the foundation, and whether the house is properly balanced. Ideally, reinforcing rods are placed vertically in the corners and walls at no more than 18-inch intervals. At the top of the walls a ring beam is made of poured concrete. Foundations are made by cementing a course of blocks slightly below ground on which the walls rest.



2. Roof: The roofs of concrete block houses in Tonga are covered with C.I. sheets. The sheets are attached to wood purlins that are fastened to trusses held on the walls in two ways. In the first, a portion of the steel rods used in the reinforcing columns is left protruding out of the ring beam. A board plate is laid on top of the beam with a hole drilled for the rod to pass through. The rod is bent over to hold the plate down. The roof trusses are then attached to the plate.

   In the second method, bolts are imbedded in the cement when the ring beam is poured. The plate is then attached by bolting it down. Of the two methods this latter is stronger, especially if washers are used between the wood and the nut.

   Roofs are "shed" (flat, sloping roof), gabled and hipped configurations.

3. Size: Concrete block houses vary in size. The smallest are approximately 12 x 20 feet, with the average being approximately 15 x 30 feet.

4. Vulnerability: The principal damages to concrete block houses observed after recent hurricanes are separation of the roof from the walls (due to a poor connection of the roof frame to the walls) and, in some cases, damage caused by the wind pushing against an unreinforced or poorly reinforced wall, causing collapse due to excessive wind pressure on the outer surface of the wall.

   In cases where houses use louvered windows, excessive pressure can build up inside the house, usually resulting in loss of the roof. Explosions occur only to very poorly-built structures.

5. Other Weak Points: Many block houses in Tonga have large overhanging eaves. In high winds, the eaves trap excessive amounts of wind underneath, creating uplift under the edge of the roof and thereby contributing to roof damage or loss.

6. Modifications for Wind Resistance: In order to improve the structural performance of concrete block housing in high winds, the following actions are necessary:

   a. Emergency measures

      --- Use more, and longer, nails to attach the C.I. sheets to the roof frame.

      --- Seal the eaves of the roof.

- --- Fasten the wooden roof truss more securely to the ring beam of the walls by using special fasteners on each connection.

b. <u>Progressive upgrading measures</u>

- --- Convert shed or gabled roofs to a hipped roof configuration.
- --- Use a roof pitch between 30-40°.
- --- Reduce roof overhangs.

If the recommendations outlined above are incorporated into the design of concrete block houses, the wind resistance of the structures will be excellent and only minor damage should occur in windstorms.

7. Modifications for Earthquake Resistance: The recommendations above also apply to construction of earthquake resistant housing. In order to be earthquake resistant, the columns and ring beams must be reinforced.

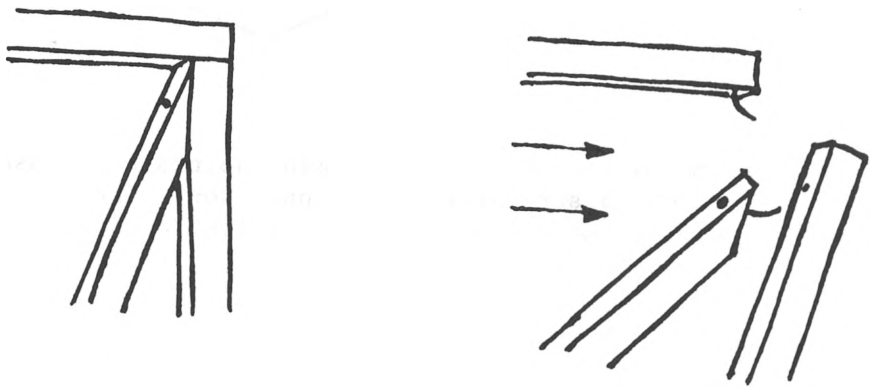
ANALYSIS OF LOCAL BUILDING SKILLS

The structural integrity of a building during windstorms and earthquakes can often be substantially improved simply by improving the quality of workmanship and detailing when the building is erected. In studying the construction of Tongan housing, a number of problems affecting the vulnerability of these structures were noted.

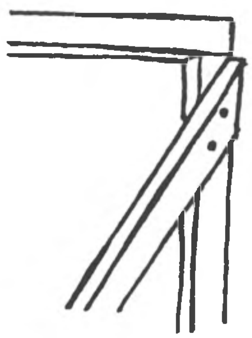
A. Carpentry Skills

1. Joints: The key problem in wood frame structures is that many of the joints are weak in terms of both design and fastening. Structurally-important joints are often nailed in tension rather than in shear. When forces are applied, the nail will slip out and the joint will separate.

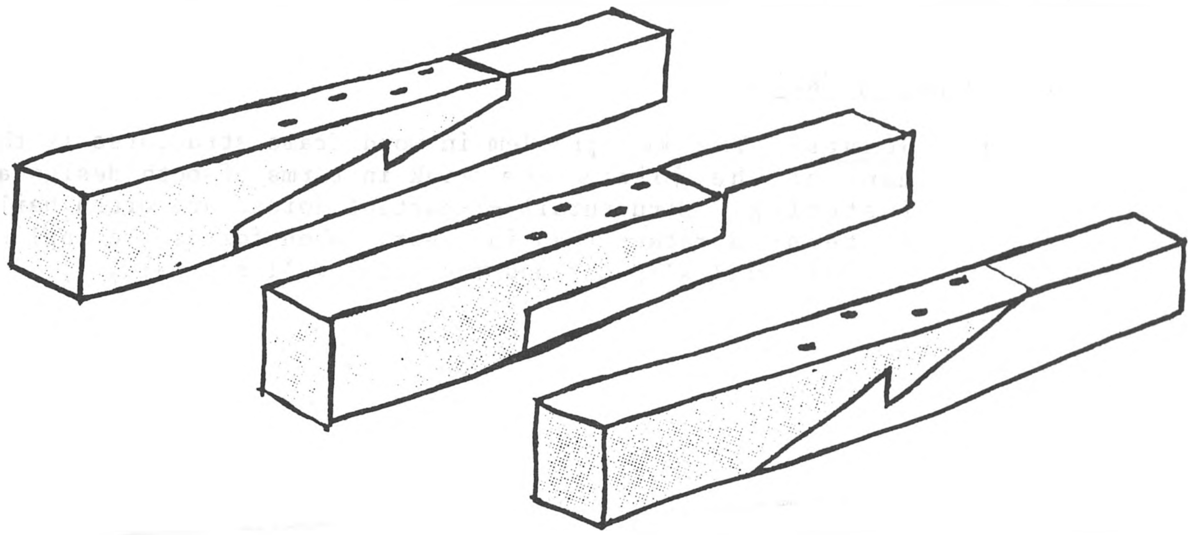
NO



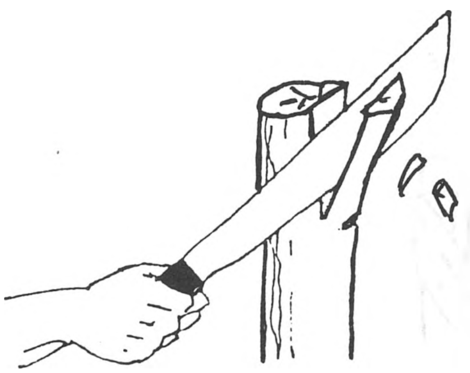
YES

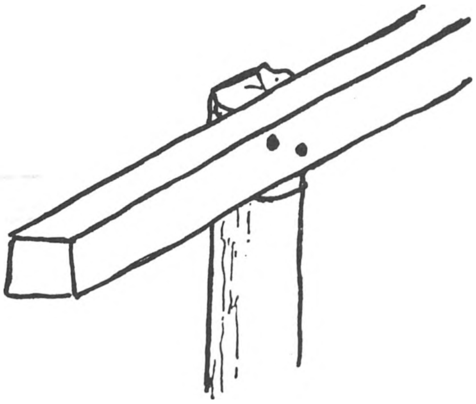


2. <u>Splicing</u>: The splicing of wood in wood frame construction is a major problem. Many splices are held together with only a nail. Few carpenters use joints that would add strength to the detail. The following splices should be used:

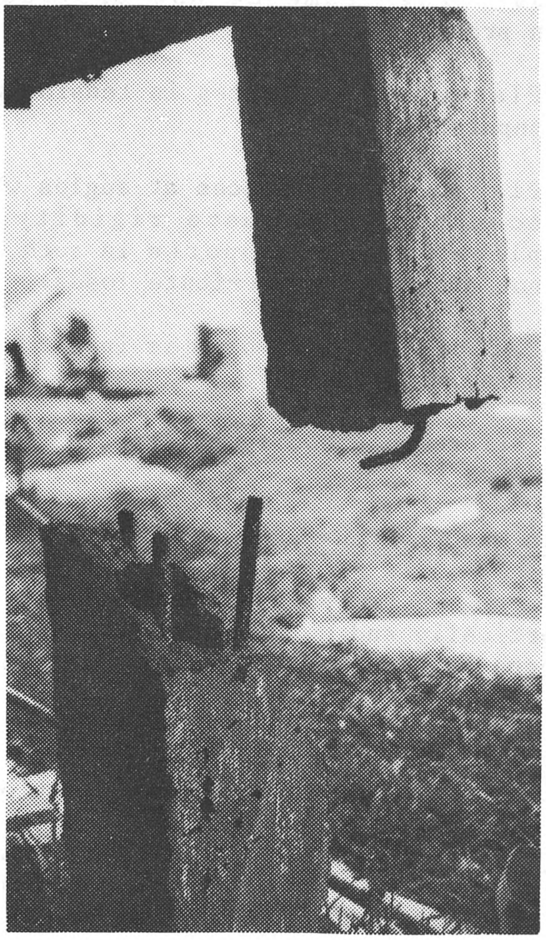


In pole construction, many joints have insufficient friction to strengthen the connection. The place where a joint will be made should be carved flat as illustrated below.



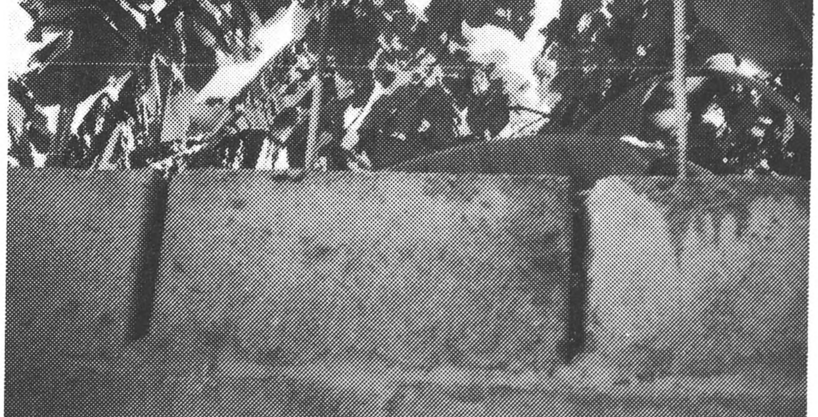


3. Poor concrete mix in the structural columns and building piers.



4. Poor connections between interior and exterior walls.

5. Insufficient mortar between blocks.



3. <u>Improper Use of Bracing</u>: Structural reinforcements in the building frame do not provide adequate strength. Common problems include:

   a. Placement of braces in tension where they can easily separate.

   b. Placement of braces at angles which are insufficient to provide adequate rigidity or resistance, and placement of supports in such a manner that they do not adequately distribute loads.

   c. Failure to use braces in critical parts (e.g., corners) of a building.

   d. Failure to use diagonal bracing in gable roofs.

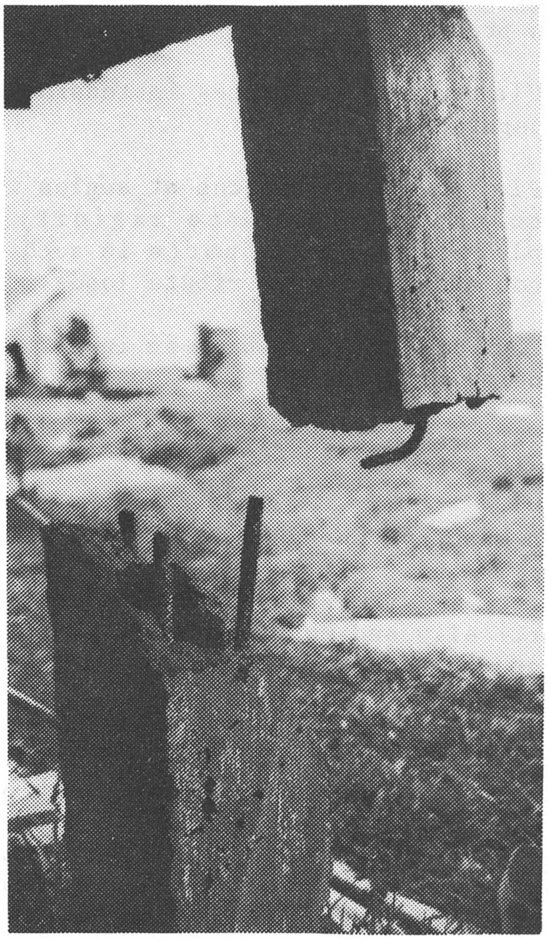
B. <u>Problems in Masonry Construction</u>

The strength of masonry is a function of the alignment of the wall (both vertically and horizontally), the strength of the mortar, and the strength of the blocks. A number of faults have been noted, including:

1. <u>Poor-quality blocks</u>: This is usually a result of lack of quality control in the local fabrication of the blocks.

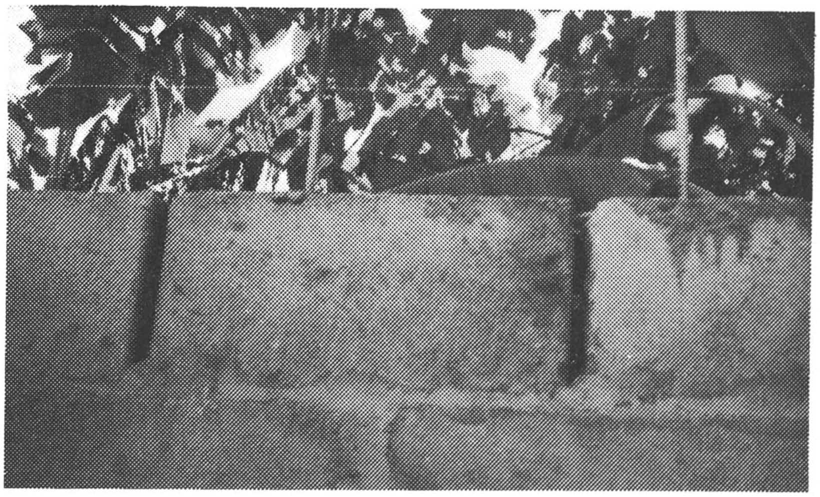
2. <u>Poor mortar</u>: There is often a tendency to reduce costs of the mortar by using less cement in the mix. This reduces the strength of the bond. Likewise, there is a tendency to make the mortar too wet in order to make it more pliable and easier to work with. This too reduces the bonding strength.

3. Poor concrete mix in the structural columns and building piers.



4. Poor connections between interior and exterior walls.

5. Insufficient mortar between blocks.



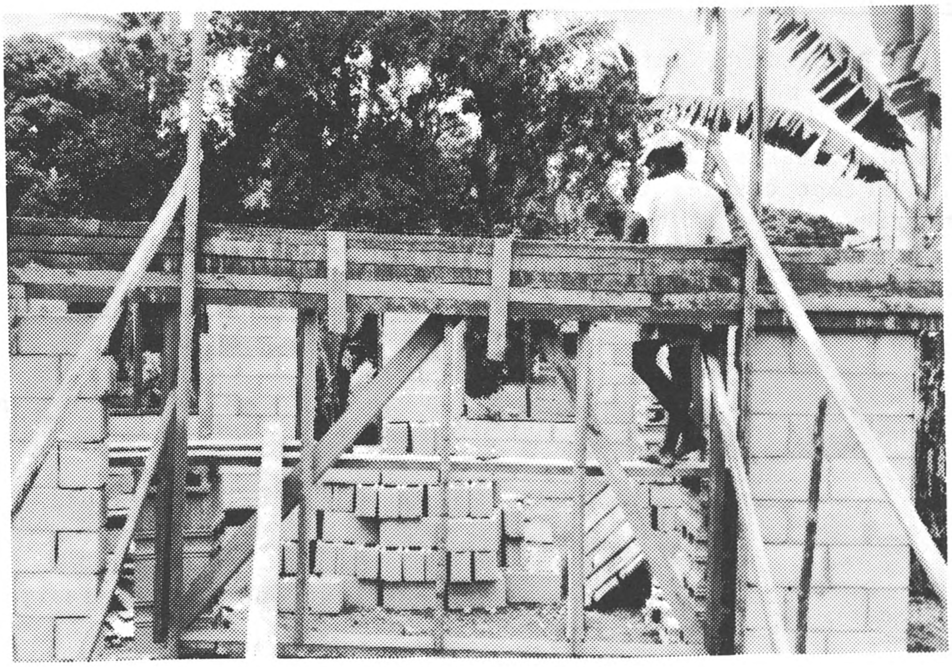
6. <u>Unlevel masonry</u> on each course.

7. <u>Insufficient reinforcement</u> in poured columns, and insufficient use of rebars placed inside block walls.

8. <u>Poor detailing</u> around doors and windows.

9. <u>Improper or insufficient foundations</u>.

10. <u>Excessive spans and questionable detailing</u> of lintels above windows.



IV. VULNERABILITY REDUCTION STRATEGIES

Vulnerability reduction measures include four types of activities: emergency measures to protect existing buildings; progressive upgrading for existing buildings; strengthening damaged buildings during repair; and improved design and construction of new buildings. Because of the large number of buildings damaged recently by Hurricane Isaac, priority should be given to the last two activities.

REPAIR OF DAMAGED BUILDINGS

Providing information on how to safely repair damaged buildings and how to strengthen them during repair should be a top priority. In the aftermath of any disaster, building repair will be the first reconstruction activity, and the government must act quickly in order to effect changes in buildings which will make them safer in the next hurricane or earthquake.

Repair and strengthening of damaged buildings require a variety of public information guides and technical assistance. The first body of information provided should help homeowners to:

--- Determine if it is safe to rebuild a particular structure;

--- Determine if it is economically feasible to rebuild a particular structure;

--- Determine what modifications are necessary to make it safer;

--- Help check for other types of damage (rot, termites, etc.).

This information should be distributed through the newspaper and through leaflets prepared by the Ministry of Works. Some of the leaflets should be handed out by the Commodities Board when people purchase building materials.

The second body of information consists of detailed instructions on how to modify and strengthen buildings. This is required in order to help guide actual reconstruction. Emphasis should be placed on how to replace damaged components; how to attach and strengthen key components and details (e.g., walls at the corner); the proper sequence for repair; and how to build a newer, safer roof and attach it correctly. Because most housing damage caused by hurricanes is related to the roof, special emphasis should be given to safe roof design and construction.

A. Requirements and Information Resources: The information requirements for repair and strengthening of damaged buildings include leaflets, posters, newspaper inserts and supplements, pamphlets, and building guides illustrating how to carry out the actual repairs.

B. Technical Assistance: A number of people should receive training on how to correctly repair damaged buildings and how to demonstrate these techniques to persons reconstructing their homes. Technical assistance should be available on each island that received major damage.

C. Information Dissemination Mechanisms: The most effective means of communicating information on repair of damaged buildings is through actual demonstration of the techniques, supported by leaflets that help those who viewed the demonstration to remember the proper sequence of events and how to correctly carry out the modification. However, there is no substitute for technical assistance, and special emphasis should be given to training a corps of people to work with homeowners and demonstrate, on site, how to repair and strengthen a damaged building.

Overall responsibility for implementation of effective repair and reconstruction activities should be assigned to the Ministry of Works. The architect's office could run a series of workshops and train local contractors in how to inspect and repair damaged buildings, as well as train their own staff in the outer islands in these techniques. Other agencies that could provide support in these activities include the U.S. Peace Corps and several private construction firms located in the country.

IMPROVED DESIGN AND CONSTRUCTION OF NEW BUILDINGS

Improved design and construction focuses on ensuring the safety of new housing by encouraging builders to incorporate disaster resistant features in buildings as they are erected. This requires creating an awareness of the need to add these features and development of a reservoir of talent and public information on how to build safely.

Many new houses will be built as a result of Hurricane Isaac. Some will be built under various hurricane reconstruction programs, but many will be reconstructed by families with little other than financial assistance. In order to prevent a recurrence of the disaster, it is imperative that special emphasis be given to disseminating information on how to build hurricane resistant housing.

The methods used to make new buildings strong are often simple and uncomplicated, and usually add little, if any, extra cost when they are routinely incorporated during construction. Design changes include:

--- Changes in building configuration.

--- Changes in building layout.

--- Changes in roof configuration.

--- Changes in roof pitch.

--- Changes in balance.

--- Changes in the building design specifications or layout which increase strength and durability and/or facilitate reinforcing.

--- Modifying certain details to increase strength.

--- Changes in design of foundations and footings.

Construction improvements include:

--- Improved quality of workmanship.

--- Improved use of building materials.

--- Increased use of reinforcing materials and components.

--- Use of better-quality materials.

--- Improved quality control.

A. Requirements and Information Resources: The requirements and information resources for improvement of new houses are essentially the same as for progressive upgrading, although the emphasis is on affecting construction before and during the building process. Specific programs may have to be modified as appropriate.

B. Coordination: Responsibility for effecting improvements in new construction should be assigned to the Ministry of Works.

C. Incentives: The most effective way to encourage improvement of new building construction is by offering increased financial assistance to homeowners on the condition that disaster resistant construction techniques be used. To affect all types of housing, the government must recognize the need to provide financial assistance to those building outside the formal construction process and develop appropriate means of providing limited funds in this sector.

D. Technical Assistance: A more comprehensive range of technical assistance and information is required to effect improvement in new construction. Initial emphasis should be given to concrete block and wood frame buildings. Provision of technical assistance at the local level should be carried out in the same manner as for progressive upgrading, but increased emphasis should be placed on training contractors. Simplified plans and drawings should be developed for families to enable them to build safe concrete block and wood frame buildings.

EMERGENCY MEASURES

Emergency measures are immediate actions taken to provide protection from an imminent danger such as a hurricane. Emergency measures focus on actions to ensure the safety of persons within a house. Activities should emphasize protection of those living in traditional and transitional housing.

Thorough planning and preparation are required in order to effectively disseminate the required information when a disaster is imminent. Preparedness planning in the housing sector should be part of a comprehensive strategy including housing, evacuation and, if necessary, emergency shelter. Some examples of emergency measures that can be taken are given in Appendix II.

The requirements for planning comprehensive emergency activities are:

A. Thorough preparedness planning. This includes a review of the actions required, the organizations that will participate, and the tools and equipment necessary, and the formulation of a comprehensive plan to guide the response.

B. Identification of public information requirements. A variety of media is required in order to disseminate the information thoroughly including leaflets, posters, pre-recorded radio announcements, newspaper inserts and supplements. These must be designed to show how to protect a house, reduce damage from blowing debris, and reduce injury in case a building fails. Information should also be available to enable homeowners to determine flood or storm surge threat, and whether they should evacuate. For those who will evacuate, an evacuation plan is required, and maps showing evacuation routes must be prepared and disseminated to appropriate organizations and news media. In addition, route markings and equipment for personnel must be prepared and pre-positioned. In some cases, hurricane shelters may be required, and they must be designated and strengthened in advance.

C. Training and technical assistance for local emergency relief officials and organizations. Not only must information on how to protect houses be distributed in advance, but also a sufficient number of people should be trained in how to use the techniques and made available to help the public on each island.

D. Information dissemination mechanisms. The most effective means of communicating information on protection of buildings is through visual media. To a limited extent, newspapers can be helpful in disseminating this information. More comprehensive information, however, will require highly illustrated booklets and leaflets. A system for distributing this information must be established in advance, and the materials for distribution must be pre-positioned for rapid distribution to these outlets prior to the occurrence of a disaster.

Overall responsibility for implementation of short-term activities is normally assigned to a government disaster preparedness agency or committee. In Tonga, responsibility was assigned to the National Disaster Committee, but comprehensive preparedness measures had not yet been instigated. In reviewing and evaluating the lessons from Hurricane Isaac, it is hoped that the National Disaster Committee can incorporate effective preparedness measures into its revised operations plan.

PROGRESSIVE UPGRADING

The overall objective of progressive upgrading is to strengthen existing housing to withstand a hurricane or earthquake. Actions focus on activities which can be carried out by the homeowner with minimal financial and technical assistance, and which do not require extensive reconstruction or modification of the existing building. Because some of the measures may require a financial input from the homeowners, activities normally concentrate on formal houses and transitional houses that are being upgraded to formal houses.

Examples of progressive upgrading measures are:

- Changing the configuration of a roof.
- Reducing roof overhangs.
- Sealing the eaves.
- Adding storm shutters.
- Installing or increasing hurricane straps in the roof.
- Installing breakaway verandas.
- Installing braces in walls and corners.

--- Improving foundations.

--- Replacing deteriorated wood.

--- Increasing the number of wall-to-ground connections.

--- Replacing short piers with longer piers that have anchoring devices.

The objective of upgrading is to reduce the need for replacement housing after a disaster. To be successful, activities should also improve livability and reduce costs of maintenance and operation.

Progressive upgrading requires a comprehensive approach and commitment from many agencies. The Government of Tonga should first develop a policy to guide the activities and an appropriate framework for implementation. In addition, the government should designate one agency to serve as coordinator.

A. Requirements: In order to encourage people to carry out housing upgrading and modification, the following are required:

1. Building Performance Standards. To provide a framework for determining which actions are appropriate for the upgrading of different types of structures, minimum building standards based on building performance and emphasizing the safety of occupants should be developed by the government for all types of low-cost housing. These will provide criteria that financial institutions can use to determine which improvements can be funded by loans, and the standards will help to identify the critical components and features of a disaster resistant building for each housing type.

   Current building codes can be used for newer types of construction, especially block and wood frame houses. However transitional and traditional buildings are not covered, and enforcement of the existing code on these types of housing is not practical.

2. Financial Assistance or Other Incentives. Some families will require financial assistance to upgrade their houses. The government should expand existing loan programs to accommodate demand. Special plans will be required to handle requests from families without clear title to their lands.

3. Information. In order to both encourage and guide progressive upgrading, a variety of information is needed including:

   a. Information about how to decide what modifications are required and practical.

b. Information on where to obtain assistance.

c. A variety of media, especially films and highly illustrated booklets, to provide detailed "how to do it" information.

To help homeowners determine whether they need to upgrade their homes and what techniques would be practical, a simple "home test" can be devised and disseminated. This test would use a numerical grading system to help determine how safe the building is, and it would show the homeowner how vulnerability could be reduced through the addition of certain components or features.

4. Technical Assistance. Most people upgrading their houses will do so on a self-help basis. To ensure that upgrading is carried out in a correct manner, technical assistance in the form of advice and demonstrations should be readily available on all islands.

5. Development of Local Skills. Some housing improvements will require the services of contractors. It is important that the government provide training to current building contractors to enable them to participate in housing improvement activities. A certification program for local contractors would be a means of improving the skill level, as well as ensuring that an adequate reservoir of talent is developed.

B. Coordination and Implementation: Overall responsibility for implementation of the upgrading of existing buildings should be assigned to a single agency. Possibilities include the Office for Disaster Relief & Reconstruction or the Ministry of Works. Other ministries or organizations that could participate include:

Construction Division, Commodities Board
U.S. Peace Corps
Private Construction Firms
Tonga Development Bank

C. Financial Assistance: New approaches should be developed for provision of financial assistance to homeowners for upgrading their homes. Primary emphasis should remain with existing financing programs and institutions. To enable a greater number of people to be served, the eligibility criteria for small loans should be expanded. This may require loan guarantees from the government or other institutions. Loans would be provided only for those improvements specified in the building standards. For persons unable to obtain loans, alternative programs where they can obtain easy access to materials or cash should be developed.

An example would be a community service work program wherein people could obtain credits toward purchase of materials at discount or subsidized prices. As a general principle, provision of direct cash grants should be avoided.

D. Technical Assistance: Some provisions for making technical assistance available on a permanent basis should be established. One method that could be tried is to form a corps of building inspector/instructors to work with people building new housing. The inspector/instructors would not only provide advice to those building or upgrading their homes, but would also work with local contractors to train and encourage them to participate. The inspector/instructors would maintain a list of certified contractors and help homeowners determine what improvements are necessary or practical, as well as help them to obtain the appropriate financial and technical assistance required.

The Ministry of Public Works is currently considering adopting a comprehensive building code. In the proposed code there are provisions for building inspectors that can easily become the more "active" inspector/instructors suggested above.

E. Technical Information Resources: At present there is no single repository for information regarding low-cost housing or the techniques and skills required to maintain and upgrade these buildings. The government should establish regional reference libraries for building and construction and should designate personnel from the Ministry of Works to work with housebuilders and demonstrate safe construction techniques.

1. A small reference library and public information materials on all types of building construction in Tonga, including both engineered and non-engineered structures and building techniques, should be established at each Ministry of Works office.

2. A national housing reference library that would be useful to architects, engineers, planners, builders, public officials, material suppliers, or anyone interested in any aspect of building construction and human settlements in Tonga, should be set up in a central location. It is especially important that data be developed concerning historic (i.e., pre-European contact) and today's vernacular construction (i.e., popular styles that have evolved in the last few generations).

V. RECOMMENDED COMPREHENSIVE VULNERABILITY REDUCTION ACTIVITIES

The following are suggestions for comprehensive activities designed to reduce vulnerability of low-cost housing in Tonga. These activities will encourage safer construction and establish better building methods as part of the normal building processes.

The vulnerability of low-cost housing can be reduced. Interest is high throughout the country and Hurricane Isaac has demonstrated the need. Thus, activities to reduce vulnerability and improve housing can have substantial impact.

ACTIVITIES

The following activities are recommended for reducing vulnerability:

A. Designate a coordinating agency.

B. Establish a coordinating committee to coordinate technical assistance and other inputs from the different government and private agencies. Members should include the Ministry of Works, the Office of Disaster Relief & Reconstruction, and those ministries and foreign agencies participating in reconstruction.

C. Prepare minimum performance standards for all types of non-engineered and low-cost housing.

D. Prepare a comprehensive set of instructional materials including materials necessary to train the staff, materials for training contractors and homebuilders, and general public information materials to promote vulnerability reduction. (A list of these materials is attached as Appendix I.)

E. Conduct workshops for housebuilders in all parts of the country. Training should stress both how to repair damaged buildings and how to build safer new buildings.

STRATEGIES FOR REDUCING COSTS TO HOMEOWNERS

In order to make housing improvements affordable, a number of cost reduction strategies and incentives should be explored, including:

A. Cost Reductions: In order to enable some families to participate, the cost of materials may have to be reduced. Program implementers should identify those materials that are critical and require a decrease in cost, and then identify methods to reduce the costs. Methods may include:

1. Payment of transportation costs.

2. Local production of components.

3. Subsidies.

B. Multiple Financial Approaches: Financial assistance will be required to ensure that every group of people can receive assistance. A balanced program with several different approaches is necessary. Possible programs include loan guarantees, subsidized loans, soft loans, and revolving loans.

C. Cooperative Activities: One of the best means of lowering the cost of housing is for families to work cooperatively. One method is the formation of a group of four or five families to help each other build or repair. The families collectively pay for the services of a certified contractor to supervise their work. Construction occurs simultaneously, thereby lessening the possibility that one family would fail to assist the others once their house has been finished. Other forms of cooperative action should also be explored.

APPENDIX I:

RECOMMENDED TRAINING AIDS AND PROMOTIONAL MATERIALS

Several separate sets of materials are required for different audiences. Many of these materials are already available or can be quickly adapted from existing resources. Also, many of the materials can be used interchangeably between sets. (Asterisks denote materials that need to be developed.).

MATERIALS FOR PUBLIC AWARENESS AND PROMOTIONAL ACTIVITIES

1. Film: "Building for Safety in Hazardous Areas": A 12-1/2 minute film explaining how the forces of hurricanes and earthquakes damage houses. This film should be used for both public information activities and portions of the instructional program. The film uses animation to show how buildings collapse and illustrates how different building features and designs affect performance.

*2. Audio-cassettes for Radio Programs: A series of audio-cassettes for distribution to radio stations, describing where and how to obtain technical information, should be prepared.

*3. Inspecting and Repairing Your House: Pamphlet to help families determine whether their houses can be economically repaired and strengthened. The pamphlet should use a checklist and numerical grading system to help homeowners determine the relative safety of a building, and it should help them determine the relative cost of various repairs they may be considering. A simplified version of the checklist may be produced and printed in the newspaper.

MATERIALS FOR TRAINING CONTRACTORS AND HOMEBUILDERS

A. Training Aids for Repairing Existing Buildings

*4. How to Repair Wood Frame Buildings: Pamphlet to illustrate repair/reconstruction measures which can improve the strength of wooden buildings in hurricanes. Special emphasis should be placed on roof designs, use of hurricane straps, and the problems of piers and anchoring the buildings.

*5. How to Repair Houses Made of Concrete Block: Pamphlet to guide homeowners in how to evaluate and repair damages, placing special emphasis on reinforcing connections between the roof and walls and how to assess cracks in the walls.

B. Training Aids for Design and Construction of New Buildings

*6. Instructor's Manual: A manual containing sections on construction techniques, building details, instructional techniques and guidelines for training including how to prepare a class, how to effectively demonstrate building details, and how to prepare course outlines for topics not discussed. Suggested course outlines and checklists for each class in a training program should be included.

*7. Introduction to Wind Resistant Construction: A Guide for Agencies in the South Pacific: Booklet to introduce the basic concepts of wind resistant construction.

*8. How to Build a Safe Wood Frame House: Pamphlet that should be prepared to serve as a guide for those building new wood frame houses.

*9. How to Build a Safe Concrete Block House: Pamphlet that should be prepared to serve as a guide for those building with concrete block.

*10. Techniques of Concrete Construction: Pamphlet to demonstrate correct techniques for preparing and using cement and concrete (can be prepared from existing materials available from VITA and the Peace Corps).

*11. Flipcharts: Training aids to amplify points made in the various booklets, for use by instructors in the classes. These charts should be prepared on cloth or plastic to make them more durable.

C. Training Aids for Upgrading Existing Buildings

*12. How to Strengthen Transitional Housing: Pamphlet to guide owners of the different types of transitional houses in how to correctly strengthen their buildings. The pamphlet should discuss the relative value of the different types of modifications and retrofitting measures possible, and provide guidance in how to determine the structural integrity of wooden components.

*13. How to Strengthen a Fale: Pamphlet to illustrate simple techniques for improving hurricane and earthquake resistance, to be developed for owners of traditional fales.

*14. How to Strengthen Wood Frame Buildings: Pamphlet to illustrate retrofitting measures that can improve the strength of wooden buildings in hurricanes. Special emphasis should be placed on use of hurricane straps and on the problems of piers and anchoring the buildings.

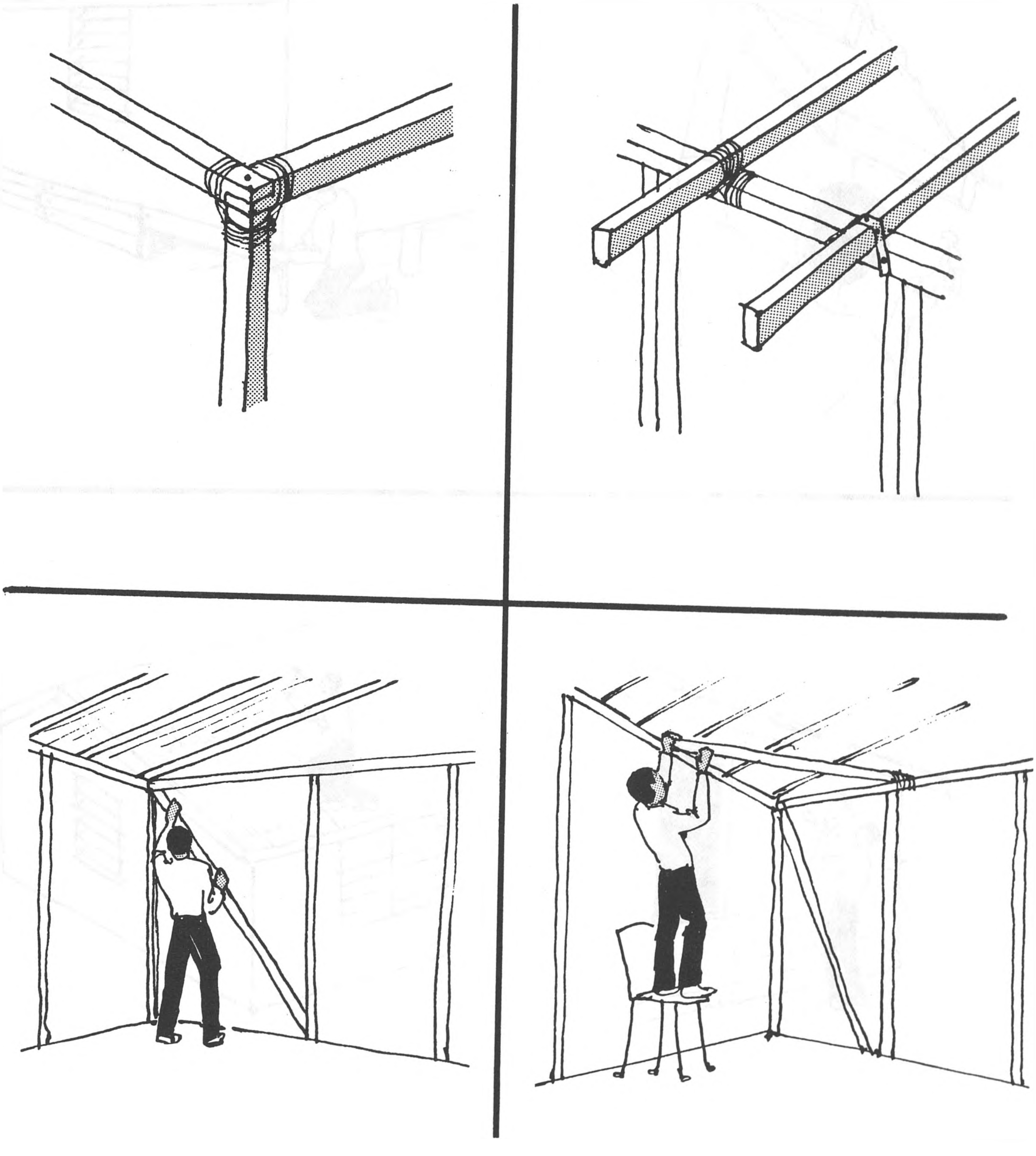
*15. <u>How to Strengthen Houses Made of Concrete Block</u>: Pamphlet to guide homeowners in how to reduce vulnerability, placing special emphasis on reinforcing the connections between the roof and walls.

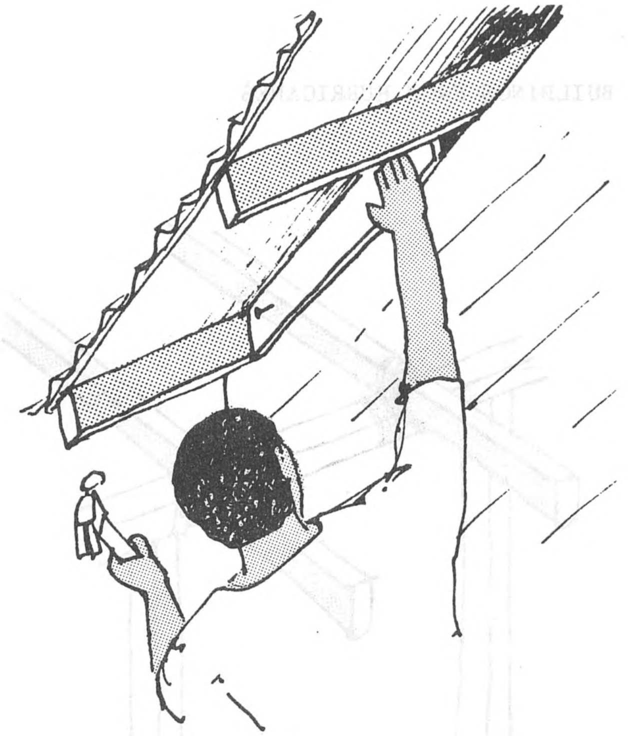
D. <u>Instructional Materials for Emergency Protection of Existing Buildings</u>

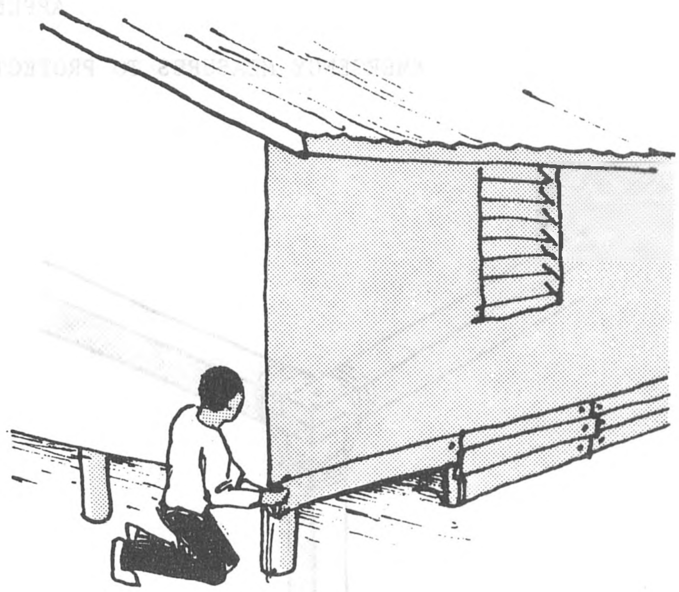
Many of the materials identified above can be used to provide homeowners with information on repairs, modifications or retrofits that can be carried out when a hurricane threatens. In addition, a special pamphlet entitled "How to Protect Your House in Hurricanes" should be developed. This would be a guide to simple improvements for all types of housing and would provide information on how to protect the building and the site, and how to determine whether or not a family should evacuate to a safer area.

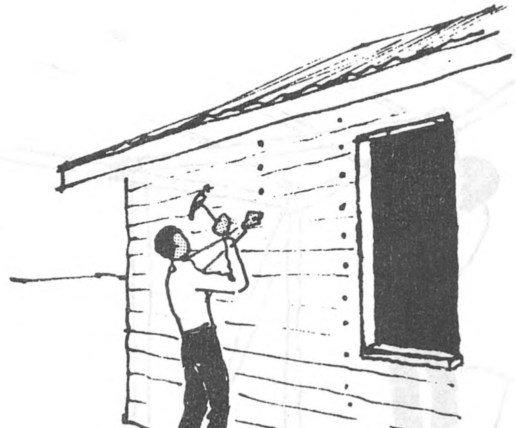
APPENDIX II:

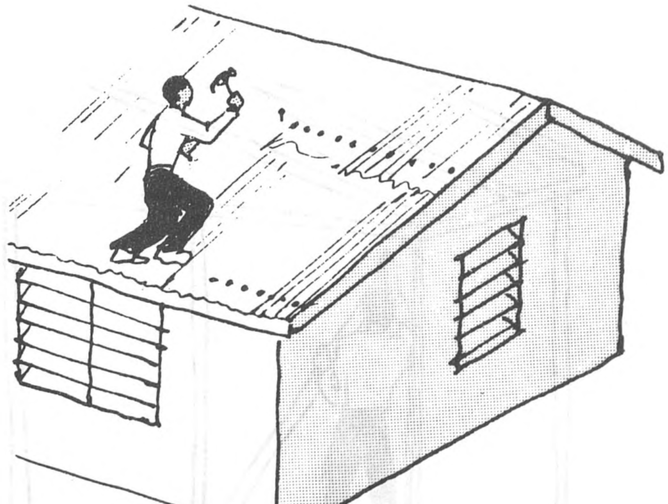
EMERGENCY MEASURES TO PROTECT SMALL BUILDINGS FROM HURRICANES

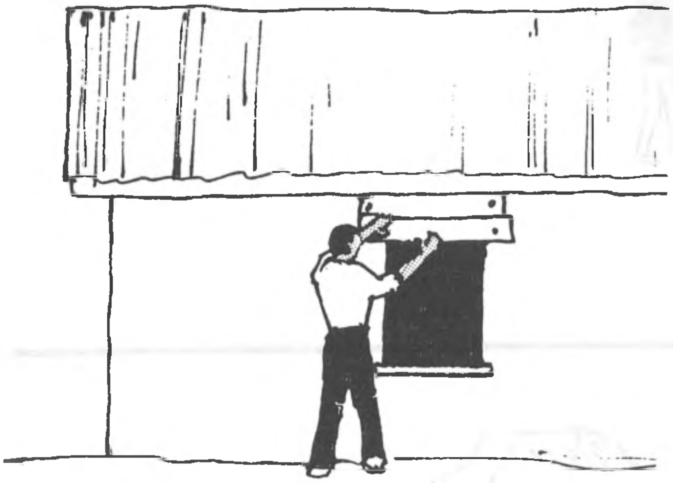


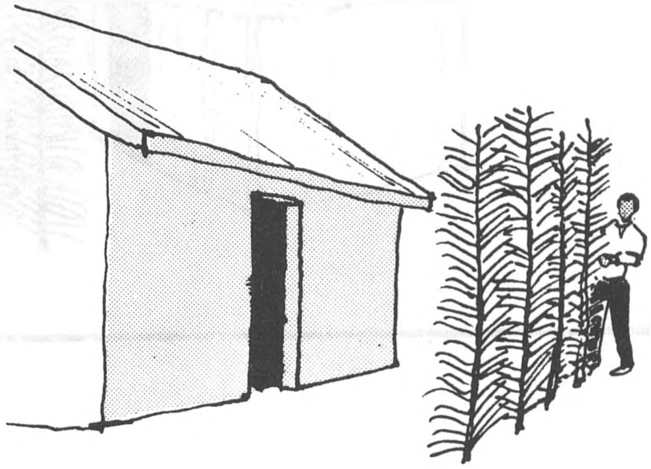


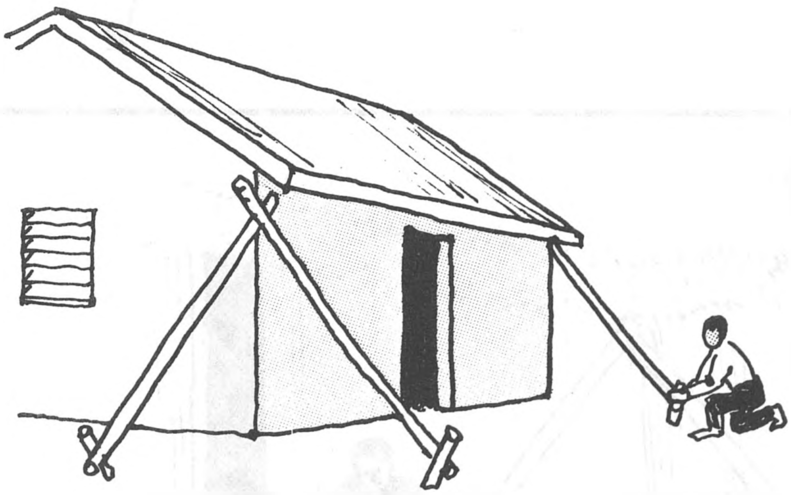


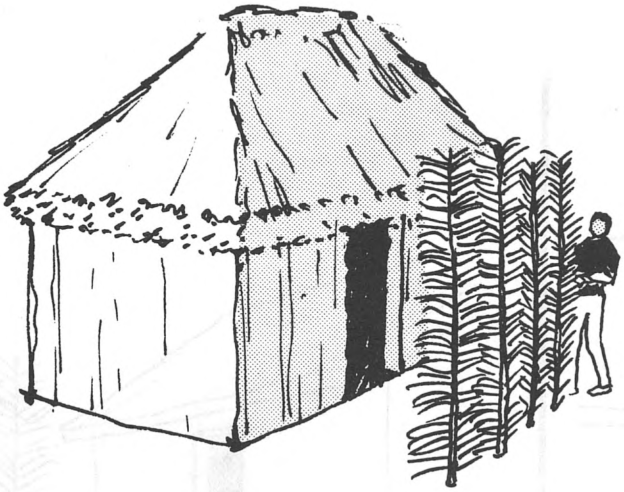


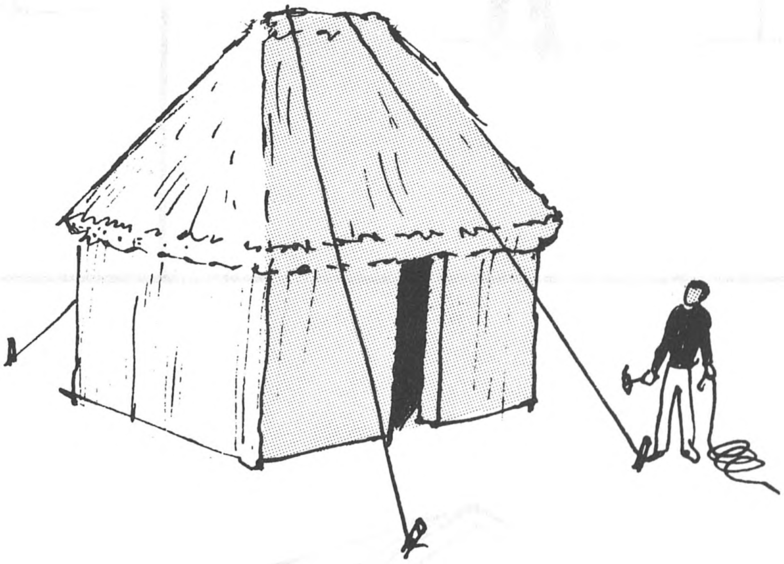


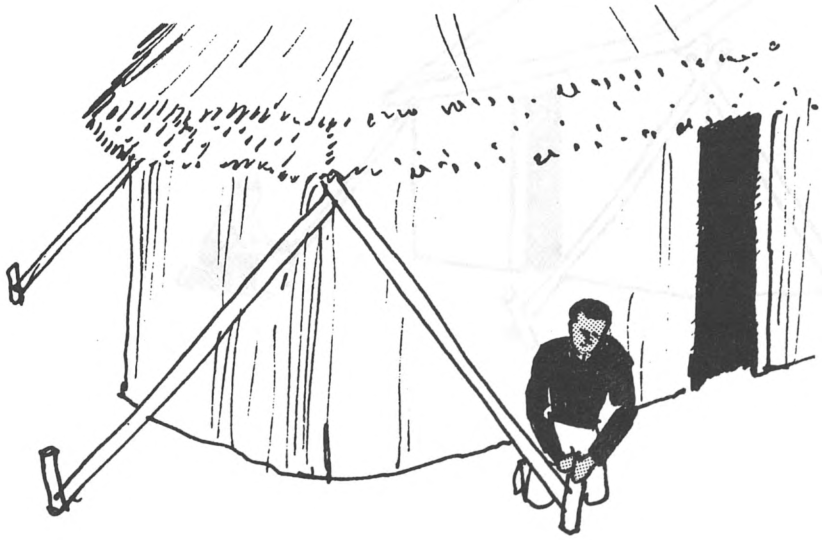








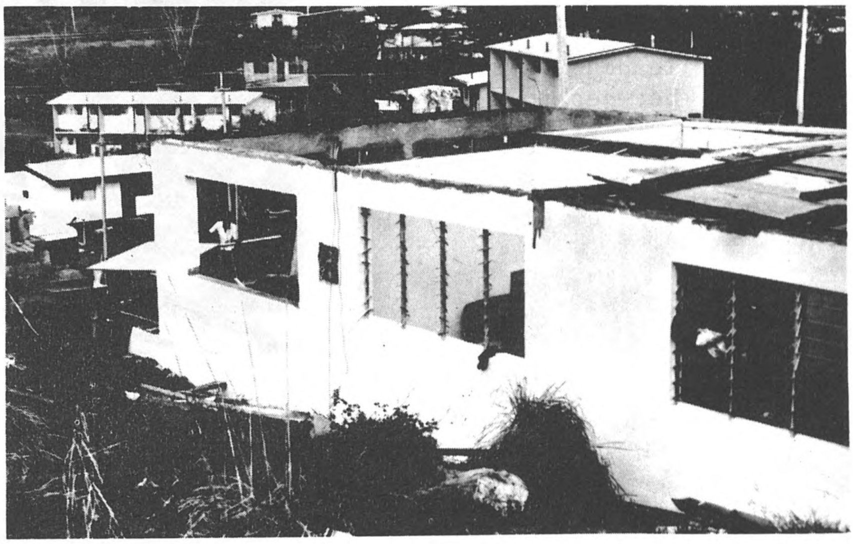




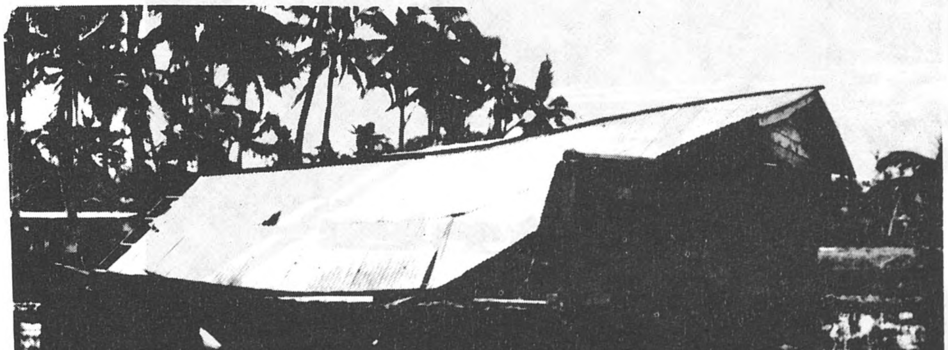
APPENDIX III:

EXAMPLES OF DAMAGE TO HOUSES AFTER HURRICANE ISAAC

Inadequate connections between roof and walls.



Inadequate connections between roof and walls.



Inadequate connections between roof and walls;

Poor masonry work;

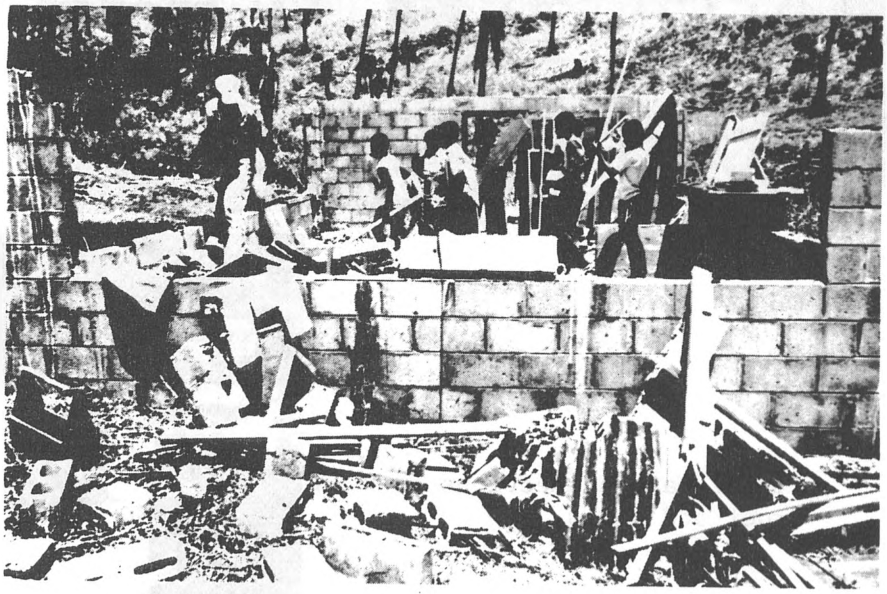
Inadequate corner bracing between walls.

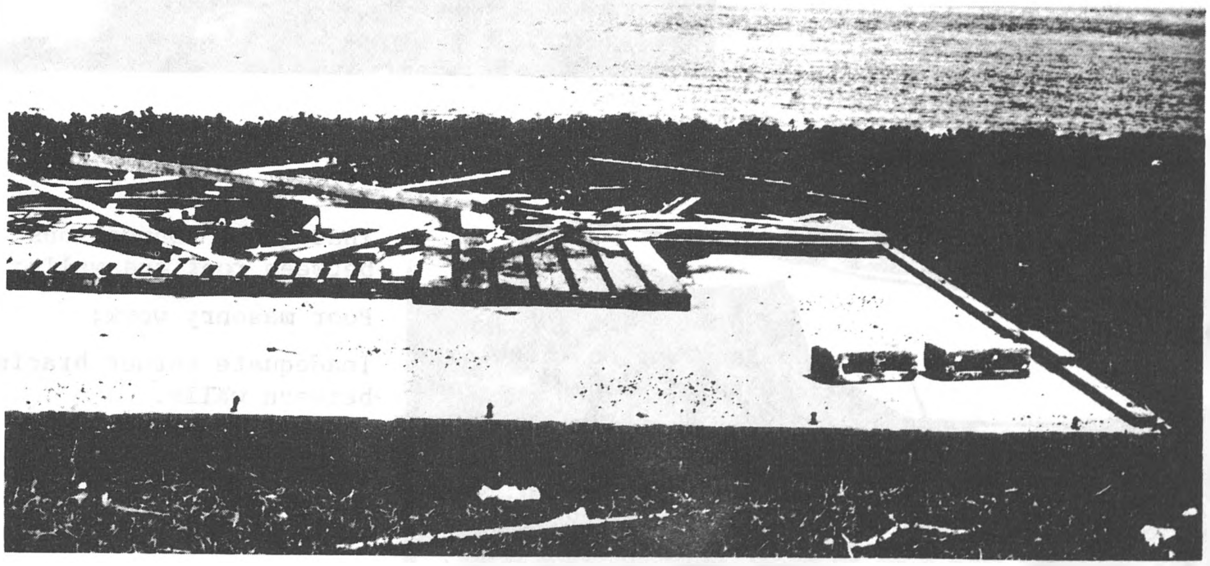
Inadequate nailing of corrugated iron (C.I.) sheets to purlins.

Poor quality masonry work;

Inadequate reinforcement;

Inadequate connections between roof and walls.





Inadequate connections between walls and floor.

Inadequate connections between roof and walls;

Inadequate connections between walls and foundation posts.

This man is holding a hurricane strap that was connected up to the wall plate. Obviously there were not enough straps used.