IMPROVEMENT OF LOW-COST HOUSING IN THE COOK ISLANDS TO WITHSTAND TROPICAL STORMS

INTERTECT
P.O. Box 10502
Dallas, Texas 75207

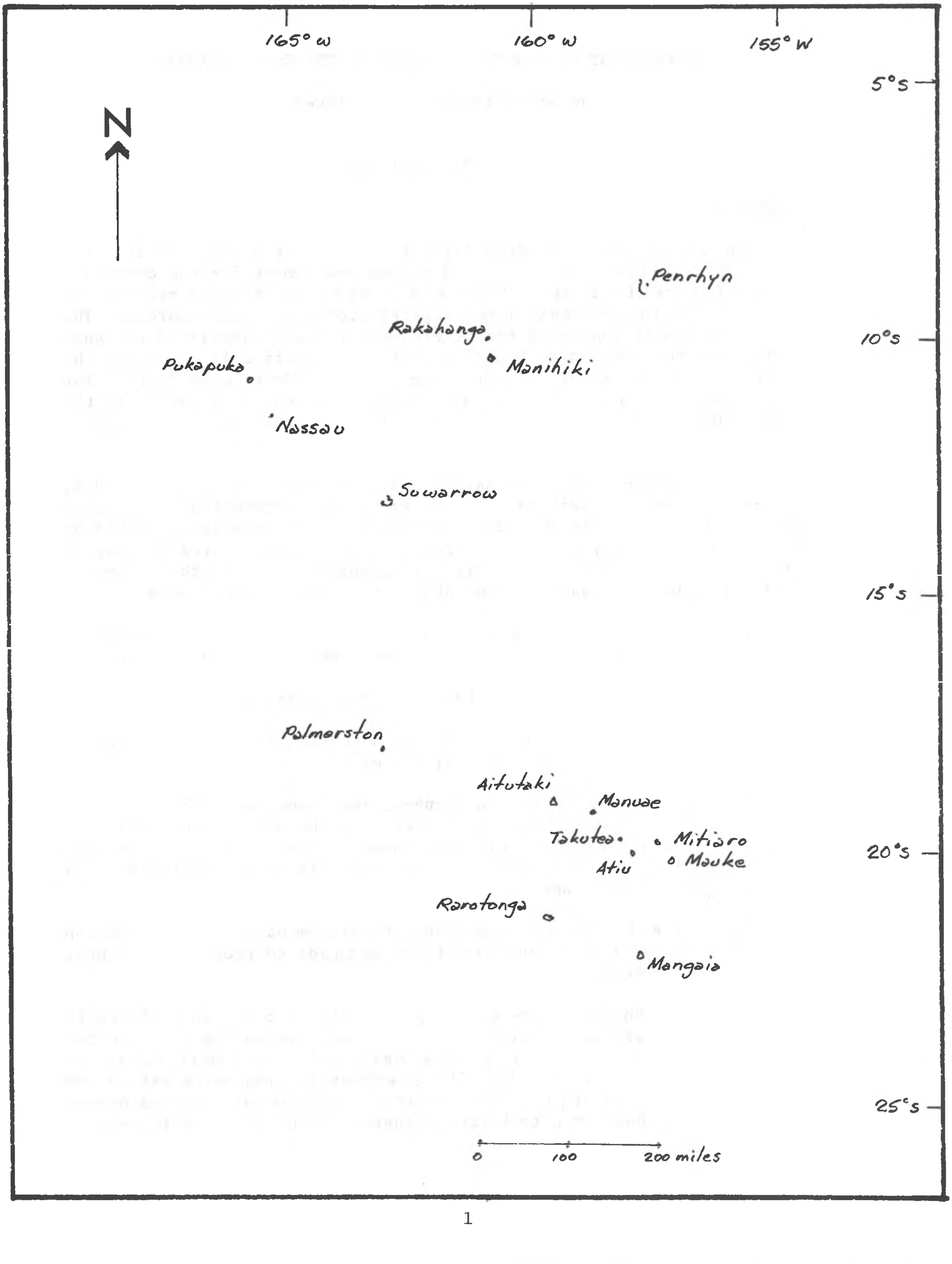
1982

Study and recommendations prepared for
Office of U.S. Foreign Disaster Assistance
Agency for International Development
Washington, D.C. 20523
Contract No. PDC-0024-C-00-1113-00

TABLE OF CONTENTS

FIGURES:

FIGURE 1 The Cook Islands



IMPROVEMENT OF LOW-COST HOUSING IN THE COOK ISLANDS TO WITHSTAND TROPICAL STORMS

I. INTRODUCTION

BACKGROUND

In early 1981, the Cook Islands Ministry of Foreign Affairs requested funding from the United States Government for the construction of a shelter on Palmerston Island which would protect its eighty-six inhabitants from tropical storms and storm surges. The U.S. Government indicated that there were no funds available for such a shelter but offered technical assistance specifically to assess the proposed Palmerston shelter design and provide recommendations for improvements, and at the same time to conduct a survey of the vulnerability of houses in the Cook Islands to the forces of tropical storms.

In October 1981, INTERTECT was retained by the Office of U.S. Foreign Disaster Assistance of the Agency for International Development (AID) to assist the South Pacific Economic Commission (SPEC) by conducting a survey of the vulnerability of non-engineered housing in the Cook Islands (as well as Fiji, Tonga and Tuvalu) to the forces of hurricanes and earthquakes. The objectives of this study were:

A. To survey the traditional housing of the Cook Islands and the construction techniques/methodologies used in order to:

   1. Classify the various building types, and

   2. Analyze the relative vulnerability of each type of building to tropical storms.

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

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

   1. Short-notice or emergency actions that can be taken to protect existing buildings (including instructions that can be disseminated when a tropical storm threatens, describing methods for improving safety and techniques for reducing damage and strengthening buildings to better withstand tropical storm forces);

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

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

D. To develop information on low-cost construction and the vulnerability of vernacular housing which can assist the Cook Islands Government in preparing their input into national housing policy aimed toward the protection of buildings and settlements.

KEY ISSUES

Housing Transition

The Cook Islands have experienced a significant transition from non-engineered traditional-style houses (called hares) made from coconut or pandanus trees towards western-style or "modern" houses made from sawed lumber, concrete and corrugated iron. Using survey data of materials used in house construction from the 1976 census, Dr. D. J. Cook shows that only 8.1% of households of all the islands still used traditional materials for roofing. Percentages by islands ranged from an almost nonexistent 0.2% in Rarotonga (with over 50% of the Cook Islands population) to 44.0% in Rakahanga (with less than 0.02% of the Cook Islands population).[1]

This changeover in building styles has several implications for vulnerability reduction efforts. Many of these buildings follow the form and style of modern houses, yet they are not built to the same disaster resistant standard. If these buildings fail in high winds, they are more likely to injure their occupants because the materials used in their construction are heavier (e.g., block or stone vs. wood and thatch).

Because the changeover is gradual, there is only limited opportunity to affect the design and construction of new buildings to ensure that they are built safely. It means as well that large numbers of people will be reluctant to modify their buildings beyond taking basic measures for personal safety, because they will find it difficult to justify the added costs of upgrading a house they intend to replace with a more modern structure.

---

[1] Dr. D.J. Cook. Resources for Building in the South Pacific, Centre for Appropriate Technology and Development, Fiji, October 1980.

Distances

One of the major constraints to both economic development and disaster mitigation efforts is the scarcity of transportation both to the Cook Islands from other countries and even more significantly between the fifteen islands that form the Cook Islands group. The remoteness of many of the islands prevents personnel from the Cook Islands Government or other non-governmental groups from providing consistent technical assistance or training. Indeed it should be noted that it was not possible for the authors of this study to visit twelve of the fifteen islands. This distance and the difficulties of transportation to the outer islands also limit the government's ability to enforce the New Zealand building codes which, at least in theory, are used throughout the country. Transportation difficulties also contribute to the lack of material resources available or greatly increase material costs.

Governmental Capacity

There is currently very little government infrastructure for responding to a disaster, for carrying out a reconstruction program, or for implementing a program to reduce the vulnerability of the existing housing stock. This may improve with development of the comprehensive disaster management plan currently being prepared with the assistance of the East-West Center. It appears likely that the Public Works Department will play a key role in programs dealing with housing.

Policy Issues

Cook Islanders are New Zealand citizens with unrestricted rights of entry into New Zealand. Under the 1965 Cook Islands constitution, the Cook Islands undertook full responsibility for external affairs and defense. Currently, most of the aid to the Cook Islands, including disaster assistance, comes from New Zealand, and clearly the Cook Islands look to New Zealand for models in disaster-related matters. Thus, proposed actions for vulnerability reduction efforts should conform to standards and practices followed in New Zealand. This is a significant factor in the implementation of recommendations made in this study.

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.

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. The Cook Islands are located in a zone of moderate risk to tropical storms and low risk to earthquakes.

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: structures that use a combination of traditional and manufactured materials in a form that follows European designs and configurations.

K. Vulnerability: a condition wherein human settlements or buildings are exposed to a disaster by virtue of their construction. Buildings are considered vulnerable if they cannot withstand the forces of high winds or earthquakes. Communities on unprotected, lowlying islands threatened by 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 THE COOK ISLANDS

HURRICANE RISK

In the Cook Islands, tropical cyclones and storm surges represent a moderate risk in general; tsunamis and earthquakes represent a low risk. The Cook Islands lie within the Pacific Basin seismic region and within the hurricane zone. The fifteen islands are spread over a very large area of the Pacific between 8 degrees and 23 degrees south latitude and 156 degrees and 167 degrees west longitude. This places the islands on the eastern edge of the "hurricane corridor" of the South Pacific. Hurricanes do occur and could strike any of the islands, but the frequency is much less than in the more western island groups such as Fiji.

The islands are divided into southern and northern groups. In the southern group, 5 notable storms between 1905 and 1939 and 10 storms between 1940 and 1969 were recorded. In the northern group, 2 storms between 1905 and 1939 and 3 storms between 1940 and 1969 were recorded (see Figure 2). Because of its latitude, the risk to the northern group is less than to the southern group. Palmerston Island appears to have the highest risk due to its latitude and longitude which place the island slightly to the north and west of the southern group.

Hurricanes threaten housing in the Cooks with:

1. Damage or collapse resulting from the forces of high winds;

2. Inundation from storm surges (popularly known as tidal waves) affecting low-lying islands;

3. Inundation from flooding on the high (mountainous) islands caused by high rainfall accompanying the storm; and

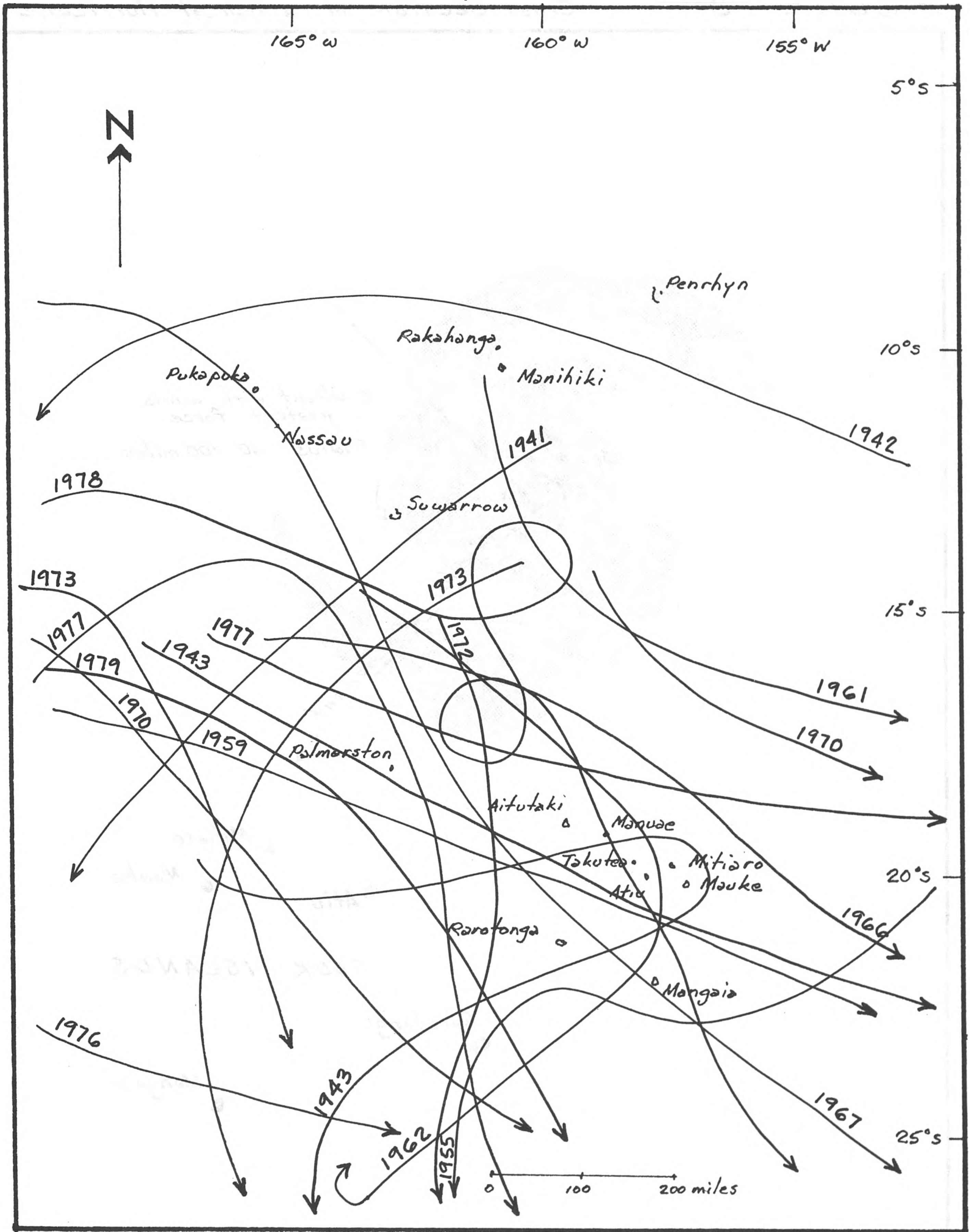
4. Damage resulting from landslides, mudslides or other displacements caused by super-saturation of the soil by heavy rainfall on the high islands.

All of these threats exist in the Cook Islands, with the atolls most at risk from storm surges. Palmerston is considered the most vulnerable to storm surges (see Appendix V for a report on "Protection of Settlements on Atolls from Storm Surges: A Case Study of Palmerston Island").

EARTHQUAKE RISK

The Cook Islands are situated far to the east of the fault system that generates the earthquakes which periodically affect Tonga

FIGURE 2 Tropical Cyclones in the Cook Islands 1939-1979



SOURCE: Tropical Cyclones in the Southwest Pacific (as amended)

FIGURE 3 Cross Section of a Typical Hurricane

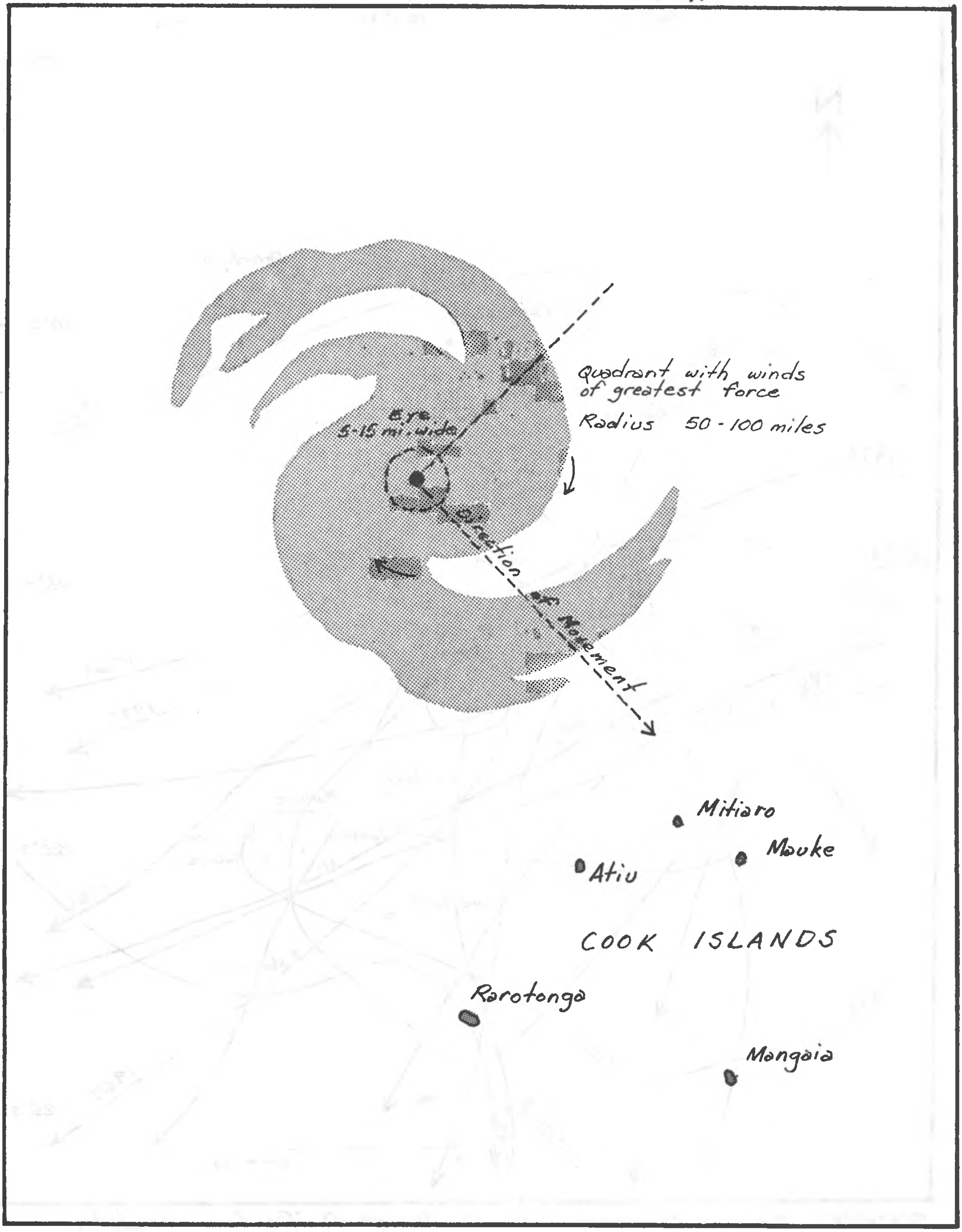
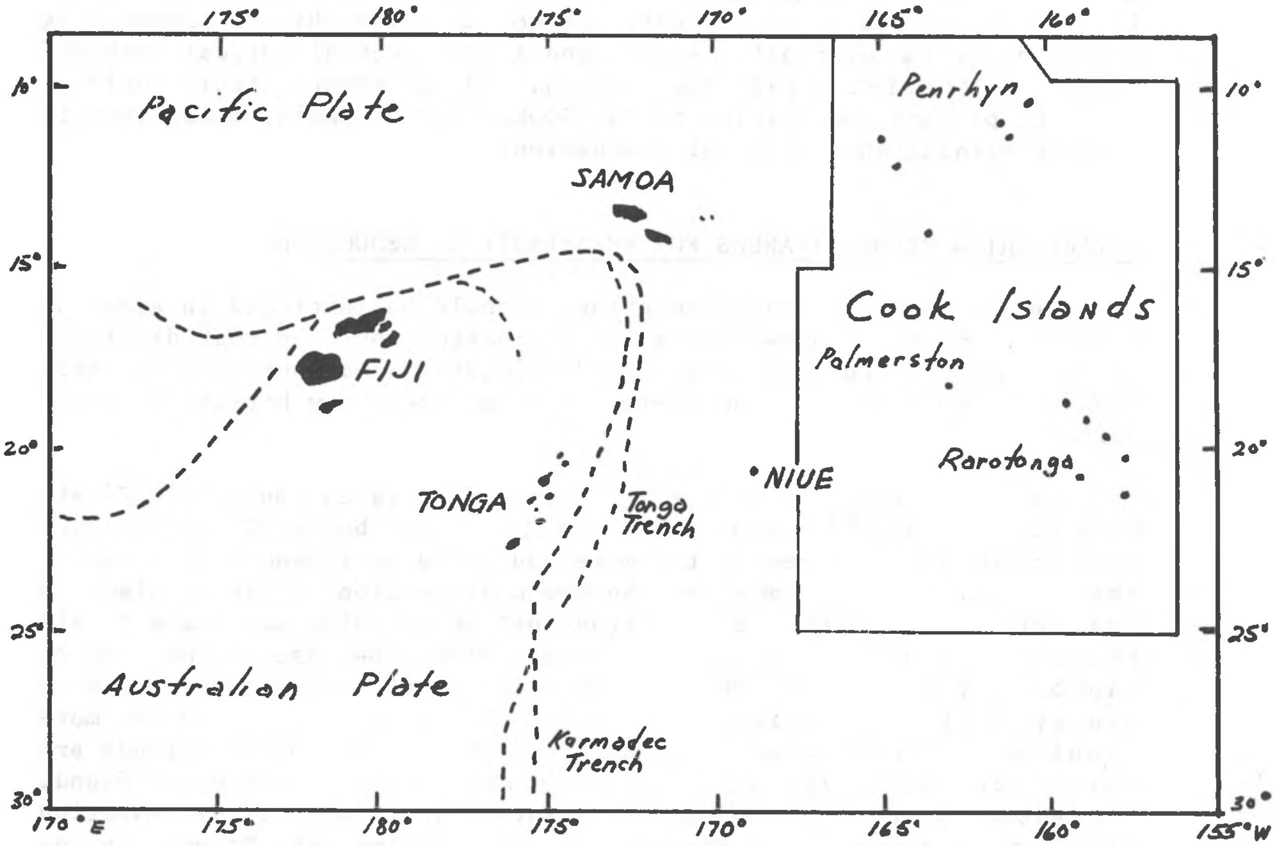
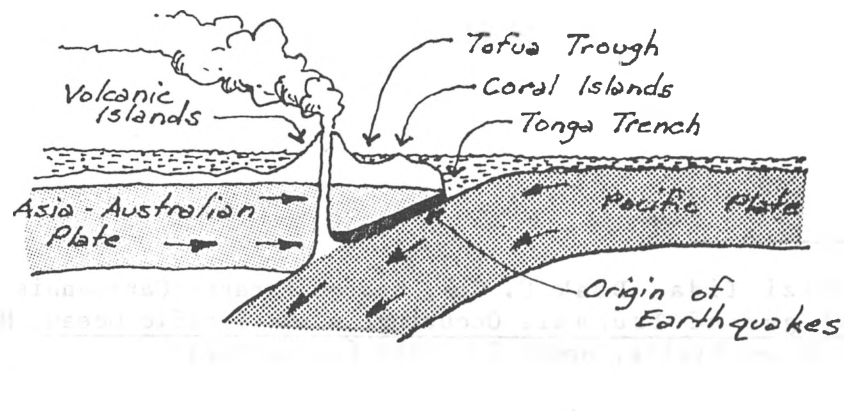


FIGURE 4 Tectonics of the S.W. Pacific





and other countries in the region. Thus earthquake risk is low.

Damage from tsunamis (seismically-generated sea waves) is of little concern to the islands because the communities are located on a small, narrow land area. As a general rule, atolls and small islands protected by coral reefs are not as vulnerable to tsunamis as large islands or coastal areas, and a review of historical records[2] shows no further cause for concern. In any event, little could be done to protect communities in the Cooks from tsunamis, other than to provide warning and notice of evacuation.

ESTABLISHING PRIORITY AREAS FOR VULNERABILITY REDUCTION

Vulnerability reduction efforts should be initiated in areas at greatest risk, in areas where reconstruction would be most difficult or costly, or in areas that are difficult to reach or supply. Also efforts will be most successful in areas where new housing is being built.

In the Cooks, there are several factors to consider. First, hurricanes usually originate in latitudes below 10^{o} south; thus hurricane risk increases the more southerly an island's position in the group. Second, most of the new construction is taking place in the southern group. Third, transport of building materials to all the outer islands is difficult and slow. Because of the lack of capability to provide emergency or reconstruction assistance (due to transportation difficulties), priority should be given to the more populous outer islands in the hurricane belt. The outer islands are also where most of the remaining traditional houses are found. Therefore, it is recommended that priority in vulnerability reduction efforts be given to the southern group, starting with Palmerston and Aitutaki, and then the remaining islands of the southern group. Upgrading should also be stressed in Rarotonga during this period but additional incentives, technical assistance and aid will be needed in the outer islands to make the modifications affordable.

---

[2] Kumizi Iida, Doak C. Cox, George Pararas-Carayannis, Preliminary Catalogue of Tsunamis Occuring in the Pacific Ocean, Hawaii Institute of Geophysics, Honolulu, 1967 (as amended).

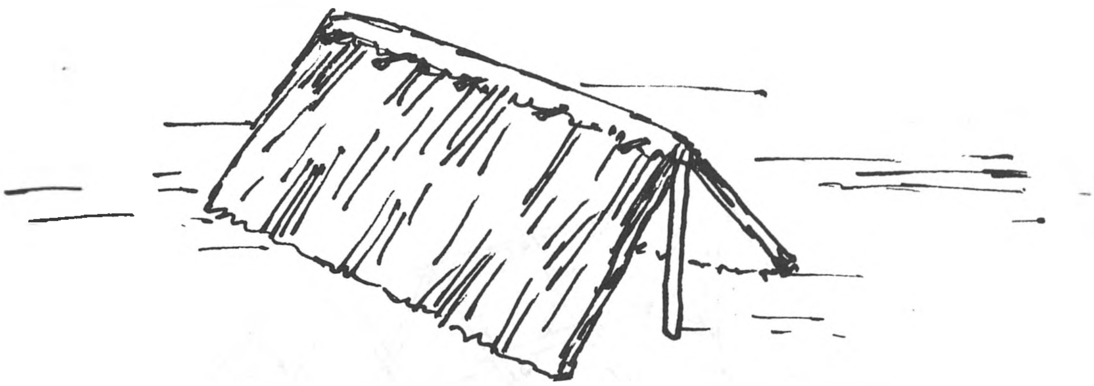
III. CONTEMPORARY HOUSING AND HOUSING TRENDS

HISTORY OF HOUSING IN THE COOK ISLANDS

Traditional houses in the Cook Islands are called "hares". Each island has developed distinctly different forms and variations of housing throughout the history of the country, although certain forms predominate in each of the island groups. The early traditional houses were mostly rectangular with well-defined side walls and a gabled roof. These designs, with modifications, can still be found on many of the islands.

The houses were built with wood posts and most were covered with pandanus leaves. On some islands the houses were thatched with coconut palms.

The "Pasaka" (illustrated below) was one type of house found on some islands that was recognized as a good dwelling for resisting strong winds and hurricanes. The Pasaka was essentially an A-frame built without wall posts and wall plates. The lower ends of the principal rafters rested directly on the ground. The frame made the building quite strong and it was not as likely to be damaged in a hurricane as were other types of traditional houses.[3]

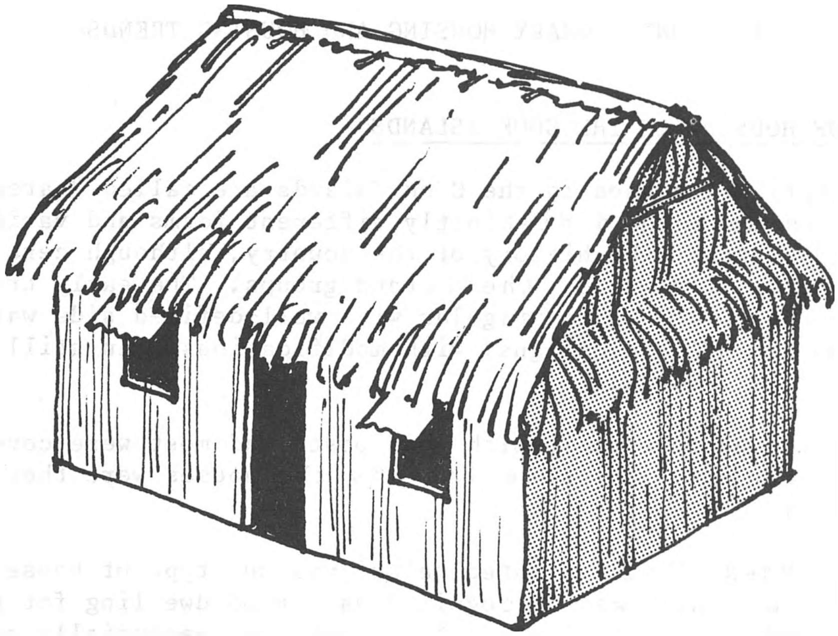


The contemporary hare borrows from early designs, especially the stronger structural elements of the Pasaka. Although wind resistance has been lost by retaining vertical walls, the addition of two king posts (main supporting posts) to help support the ridge pole adds strength to the frame and allows a steeper roof pitch which makes the buildings cooler. Records of damage from recent hurricanes are incomplete but observers have noted that, even though hares receive considerable roof damage, the frame remains intact and few occupants have been injured.

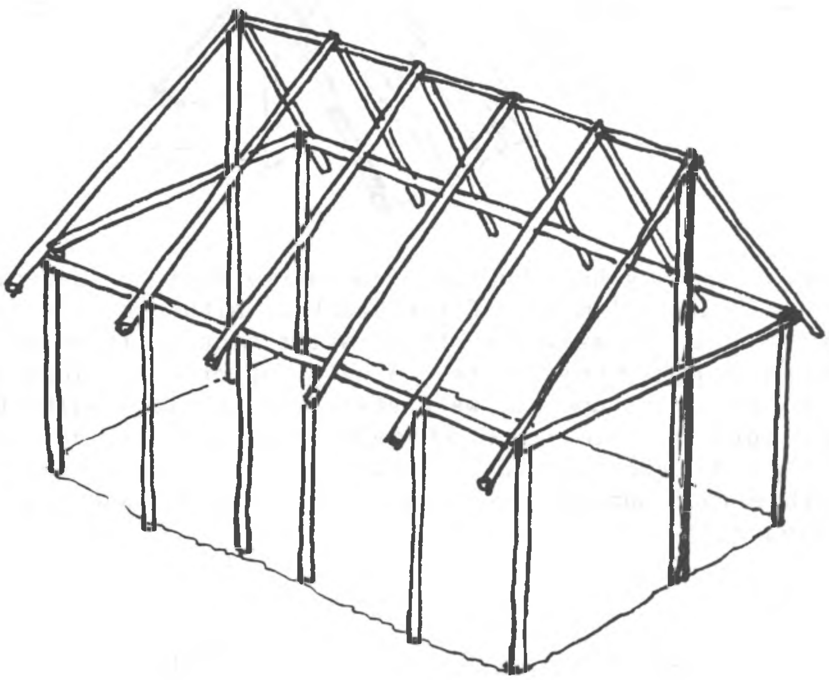
---

[3] Hiroa, T.R. Ethnology of Tongareva, Bishop Museum: Honolulu, 1932.

Modern Hare



Frame for Modern Hare



The arrival of the missionaries saw the introduction of lime burning and the use of lime as a cement. The London Missionary Society Church at Avarua is an example of a structure built from coral boulders cemented with a mortar of lime, beach sand and sea water. The walls of this building are one meter thick. Other churches were built by sawing cemented coral debris into blocks and concreting them together with the lime mortar. Houses were also built in this manner.

In 1950 all the pandanus palm on Rarotonga was destroyed by insects. This had the effect of hastening the transition from traditional to more contemporary materials. In 1951 the use of lime was revived by the Superintendent of Works and, in the period from 1951 to 1961, approximately 42% of the government's building program was carried out using "coralite", as it was termed. The cost of lime was about 22% that of cement.[4] There appears to have been little or no lime burning in the last 5 to 10 years, and coralite buildings make up only a small percentage of the total housing in the Cook Islands today.

After the introduction of lime, changes in housing styles and building materials eventually followed overseas trends. This evolution has been further accelerated in the last decade by increased migration to and return from New Zealand. Today many people go to New Zealand to work for several years, earning enough money to purchase a house in kit form and ship it home. In 1978 the importation of building materials and housing kits accounted for 7.6% of total imports.[5]

---

[4] Dr. D.J. Cook, Op. Cit.

[5] Ibid.

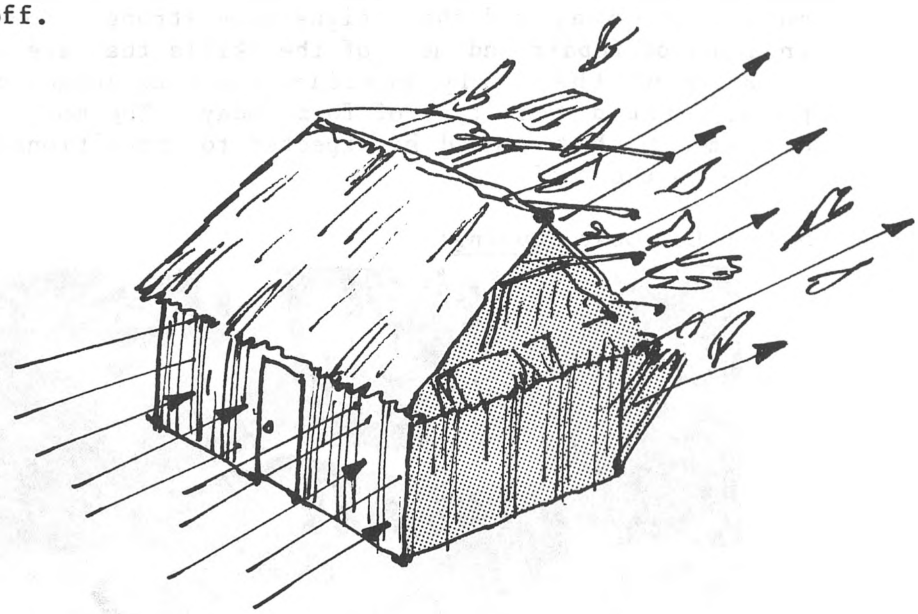
CONTEMPORARY LOW COST HOUSING

Housing in the Cook Islands today can be classified into one of three categories: traditional, transitional or modern.

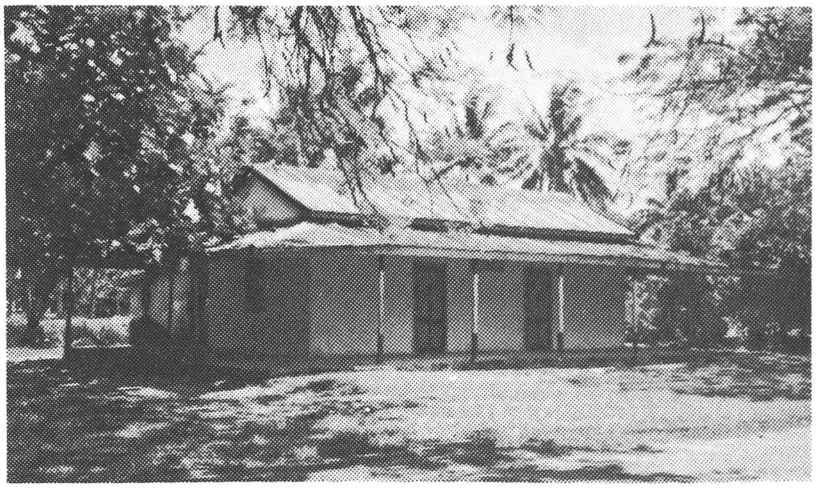
A. Traditional Housing:

The traditional house or "hare" is a beautiful housing form well suited to the climate and traditional way of life, but it is rapidly disappearing throughout the Cooks. Very few hares built entirely of traditional materials are still found, although there are many buildings that use traditional materials and designs for the main components and manufactured materials for other elements of the buildings. The most prevalent examples are buildings which use traditional materials for the walls and roof frame but cover the roof with metal sheets.

Unfortunately, hares built in the traditional manner are very susceptible to damage from windstorms because wind can easily penetrate the walls, deflect upward underneath the roof and lift it off.



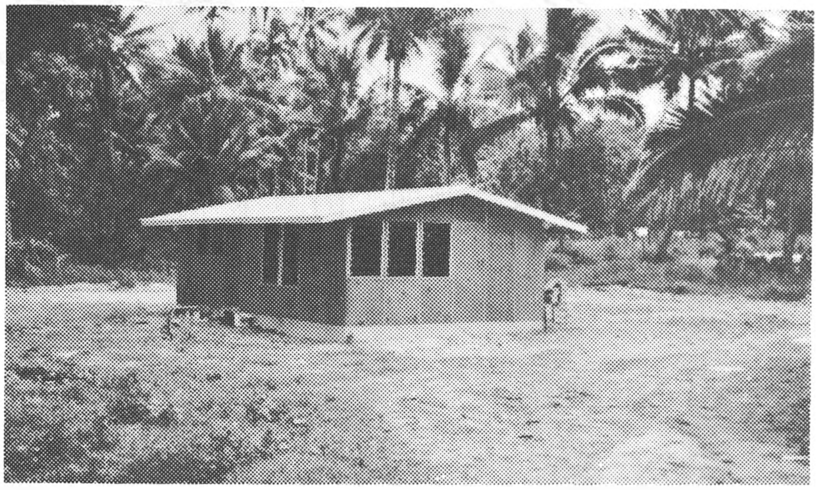
B. <u>Transitional Housing:</u>



Transitional houses are buildings that illustrate the architectural transition between traditional buildings and more modern forms. The term "transitional" in this case refers to the architectural style rather than to a phase of the building itself. In the Cook Islands most of the transitional buildings represent architectural styles and building methods that were introduced during the last century in European architectural forms. There are several popular variations seen in the Cooks including buildings made with coral and lime as well as some wooden buildings erected during the past fifty years.

These buildings tend to be fairly hurricane resistant as they are generally made of heavier materials, the quality of workmanship was good, and the designs were strong. However, many are in need of repair and many of the skills that are evident in the details of the early buildings are no longer practiced when people build this type of form today. The most prevalent type of damage that could be expected to transitional buildings is damage to the roof.

C. Modern Low-Cost Housing:



Modern houses are usually built by contractors, although many (especially wood panel buildings) are built by the owners, particularly if they have acquired building skills and capital from a stay in New Zealand. Many of the contractor-built houses are financed by the Development Bank*; these must conform to the New Zealand Building Code and must be inspected and approved during construction. Unfortunately, there is little inspection outside Rarotonga. There are no government programs to provide housing directly or indirectly to the public. However, the Public Works Department provides design assistance and standard plans to persons wishing to build houses and makes these available to contractors throughout the country. Still, contractors often modify the plans and some of the disaster resistant features are not completely incorporated in the final buildings.

MATERIAL CONSIDERATIONS

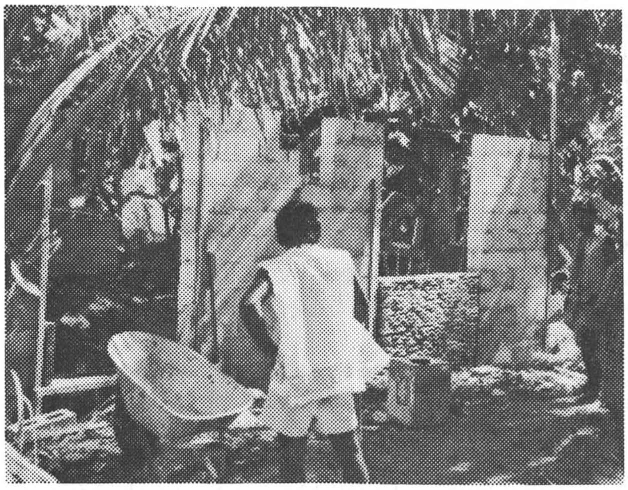
In the past, most hares were built of indigenous materials found on the islands. With modernization and clearing of large portions of

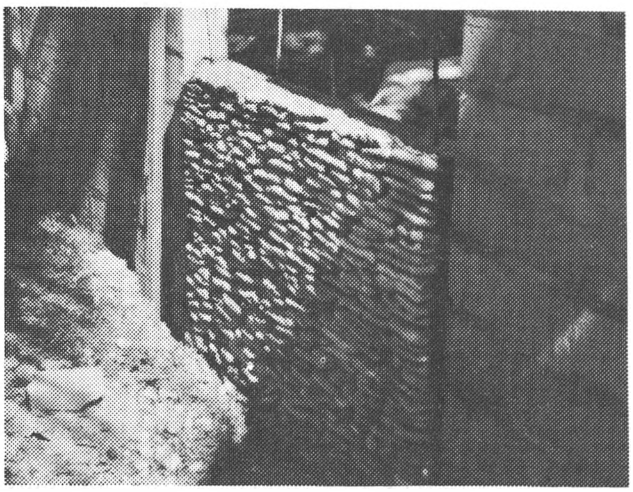
* Special fund for development offered by the Post Office Savings Bank, funded by the Asian Development Bank.

the islands for planting tropical commercial crops, most of the trees normally used in construction are gone. Most houses now use building methods that require imported materials such as concrete, wood, or metal sheets. This raises the cost of construction far above what it would be if more locally available materials were used.

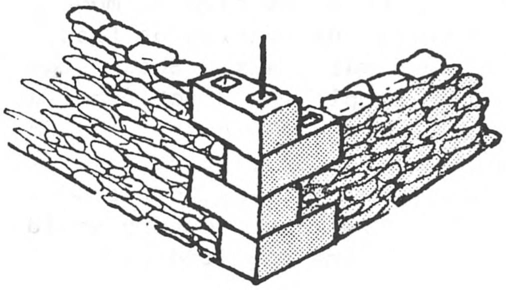
Should a disaster occur, the cost of reconstruction of modern structures will be many times higher than reconstruction of traditional buildings which rely on indigenous materials. Should the disaster occur in the outer islands, most people would not rebuild traditional homes but would modernize. Reconstruction costs will be further increased if it is necessary to transport large quantities of manufactured building materials from the larger islands to the more remote areas. This also means that the total time for recovery would be increased due to transport delays and the time required to build more formal buildings.

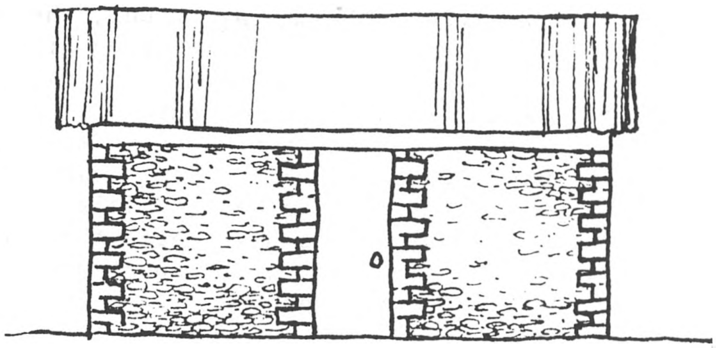
For this reason it is important that consideration be given to developing low-cost housing designs and building methods that incorporate the popular features of modern housing, yet can be built with a high percentage of locally available materials. Several of the building methods introduced in the last century and still used in transitional buildings could be improved upon and used to build modern-style buildings (e.g., lime and coral). Another option would be to use a combination of manufactured and locally available materials. An interesting method which could be applied is the use of coral and concrete block now being tried in Tuvalu. In this method, coral rocks are substituted for concrete blocks in non-structural parts of the wall. This provides an attractive, strong wall at a reduced cost.





If adequate reinforcement is used, there is no reason why this type of construction would not be safe. In fact, even more use of coral could be employed safely as shown below.





Save the Children Foundation in Tuvalu has asked a consultant in Fiji to undertake a coconut stem utilization study, part of which is to determine the potential for using coconut wood in housing. (Stems are now used in the roof frame and in the non-load-bearing parts of some houses.) If coconut palms can be used, this would provide a much-needed source of wood to keep building costs down. Thus, the results of this study should be shared with the Cooks.

USE OF CONTRACTORS

In recent years there has been a trend toward increased use of contractors to build or supervise construction. This is due in part to the demand for more modern buildings made possible by Cook Islanders working abroad and saving money for a home in the islands. The majority of concrete block and wood panel housing on both Rarotonga and the outer islands is built with at least some input from a tradesman. The number of contractors is very small but growing, and many men are receiving training and experience overseas. A contractor may be asked to build the complete house and provide all the labor. In other cases he may only be hired to provide periodic advice or to build critical components.

The increased use of contractors is an important consideration for housing vulnerability reduction because they build the heavier and more costly buildings and because more sophisticated buildings will require more professional input in order to be built correctly. Efforts should focus on upgrading contractors' skills and capabilities. Without full participation by contractors, vulnerability reduction will be difficult to achieve.

IV. VULNERABILITY ANALYSIS OF 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 a function of 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° 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)

--- Center of Gravity (walls should be low)

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

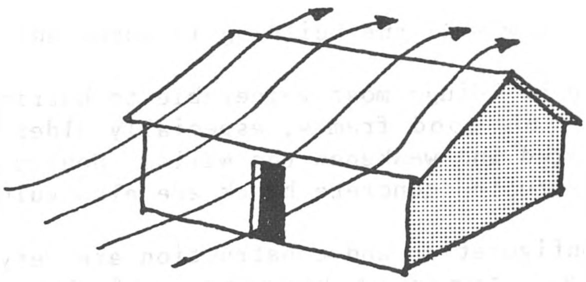
In areas of seismic activity, the most vulnerable houses are the unreinforced or poorly constructed concrete block and stone wall or other types of masonry buildings. Theoretically, block housing is fairly easy to reinforce to a basic standard of earthquake resistance and some block houses in the Cooks do use adequate iron reinforcement. However, the quality of the blocks in many areas and the workmanship and detailing, especially ring beams, 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.

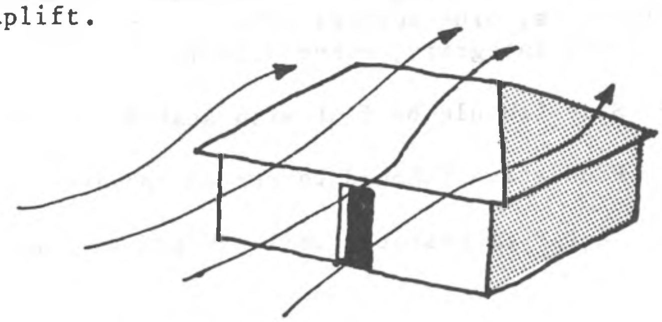
COMMON PROBLEMS

There are a number of problems often found in housing in the Cook Islands. The following section describes some of the more popular styles and details that have been identified as being dangerous in either hurricanes or earthquakes.

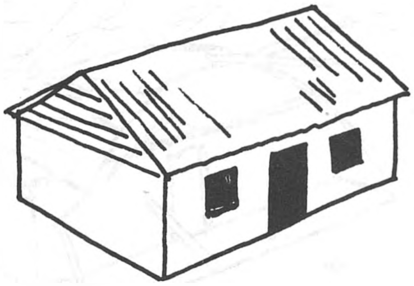
A. Roof Configuration: Many buildings in the Cooks utilize a shallow gable roof such as the one illustrated in the figure below.

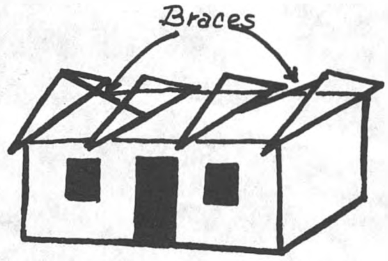


For both hurricane and earthquake resistance, a hipped roof such as that illustrated below is preferred because it reduces the total surface area exposed to wind-induced uplift.



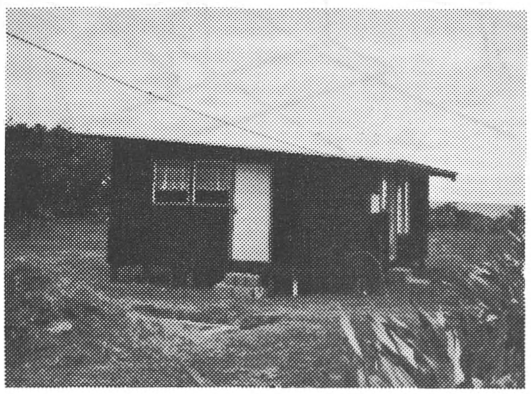
A gable roof may be used, however, if the angle of inclination of the roof is approximately 30-40° (the steeper angle reduces suction), if the roof trusses are adequately braced so that they do not collapse when forces are applied along the longitudinal axis of the house, and provided that the gable is sufficiently reinforced so that it does not fail and collapse when pressures are exerted from either an earthquake or a hurricane.

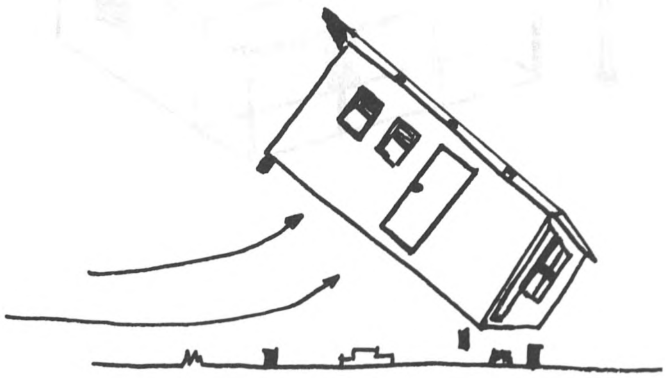




The roofs of hares are usually in a gable configuration but the angle of inclination meets the requirements for wind resistance. However, in the other types of houses the roofs are often too flat. The lack of roof truss reinforcing and poorly-built gables are common to many buildings.

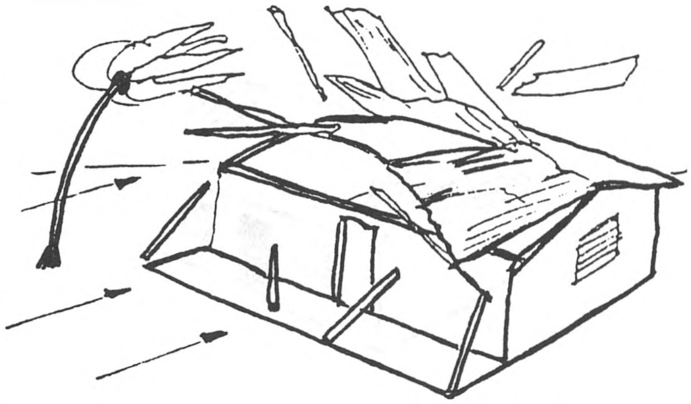
B. <u>Piers</u>: Many of the smaller wood frame buildings are placed on short wooden posts in order to allow air to circulate underneath and help keep the house cool, as well as to reduce insect damage to the walls. In hurricanes, fast-moving turbulent air can pass under the structure, lifting it off the piers and contributing to its collapse.



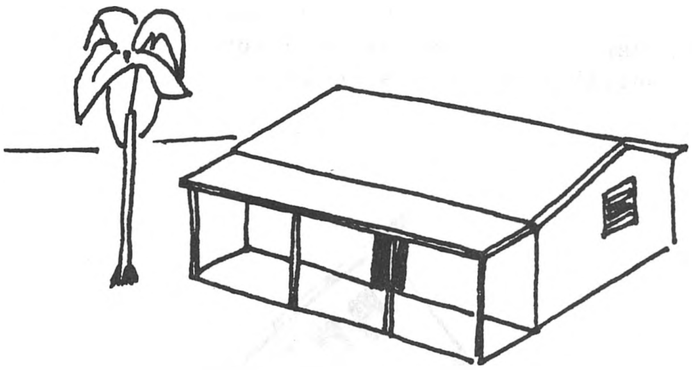


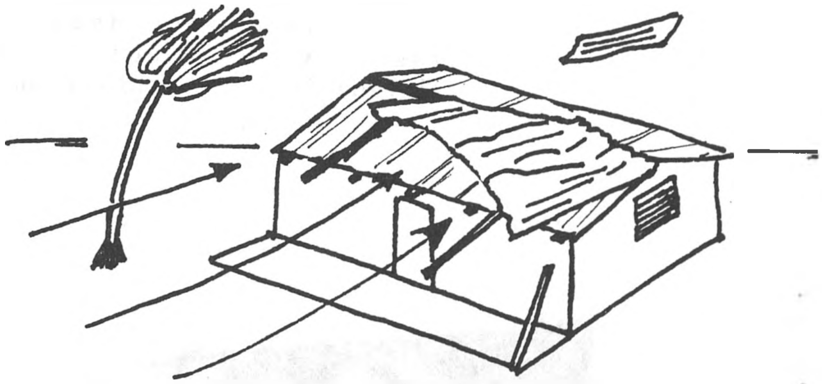
C. Verandas: The manner in which a veranda is constructed affects the vulnerability of a house. If the veranda is attached to the roof structure and traps wind underneath, the entire roof can be lifted off the house.

A popular veranda and its pattern of failure is illustrated below.

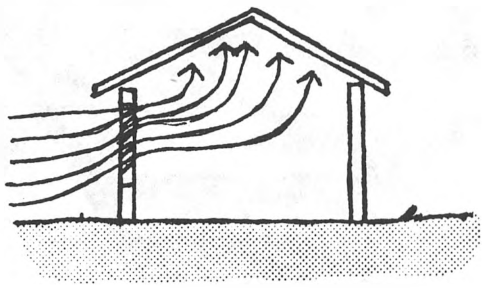


If this configuration is to be used, the connections between the veranda and walls and roof structure must be designed in such a way that the veranda can break away from the main structure of the house without severely damaging the rest of the house.

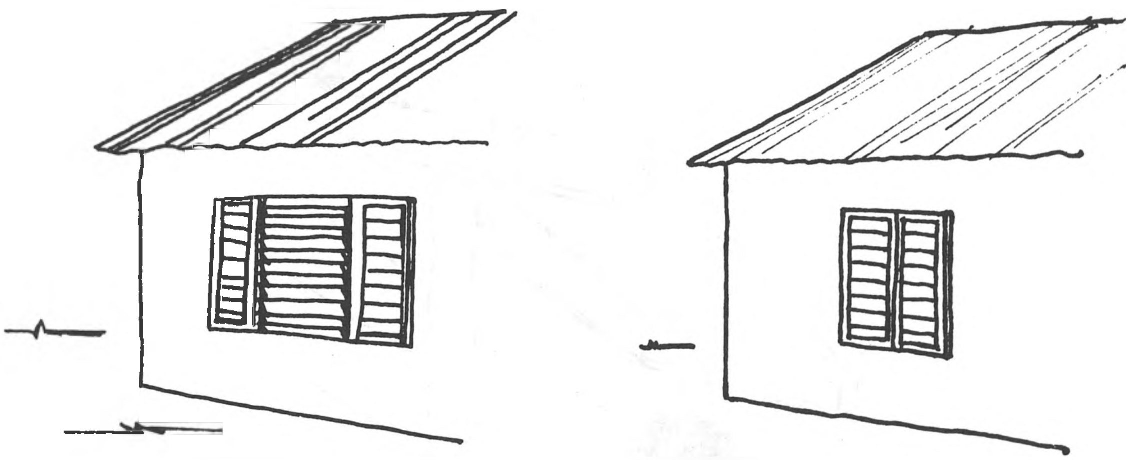




D. Louvers: Unless louvers are completely sealed off during a hurricane, excessive wind can enter the building, increasing the upward pressures on the roof.

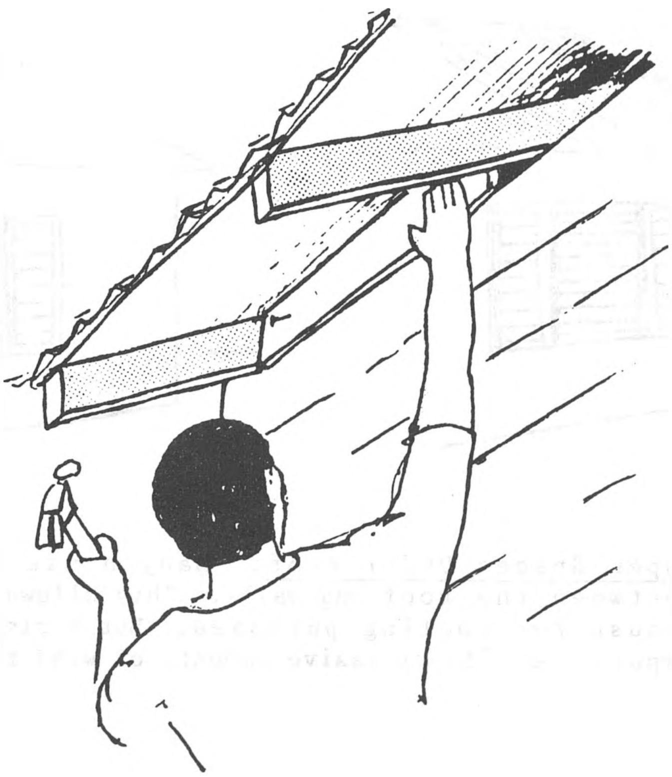


In theory, it should be possible to board up these areas before a hurricane, especially if adequate warning is given. In practice, however, when a warning is received, wood becomes scarce and it may be difficult to obtain the materials necessary to seal off these areas. The ideal solution is to install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



E. Open Spaces Under Roof: Many houses 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 increase the outward pressure on the walls and roof.

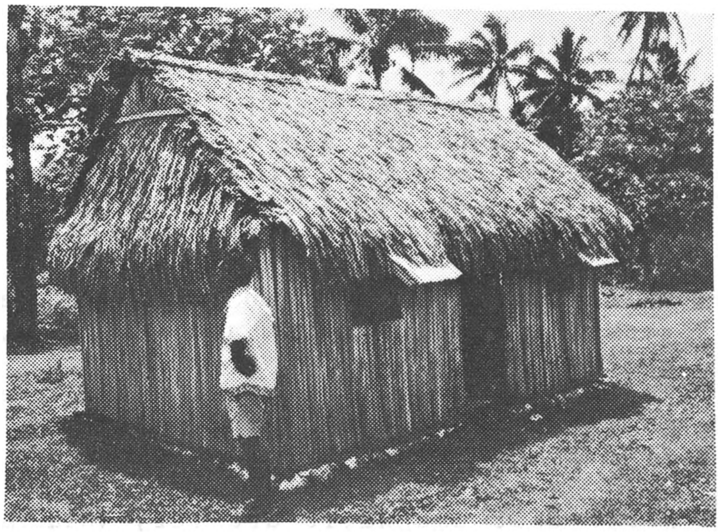
The best solution to this problem is to seal the eave as illustrated below. This will also help reduce the uplifting forces at the edges.



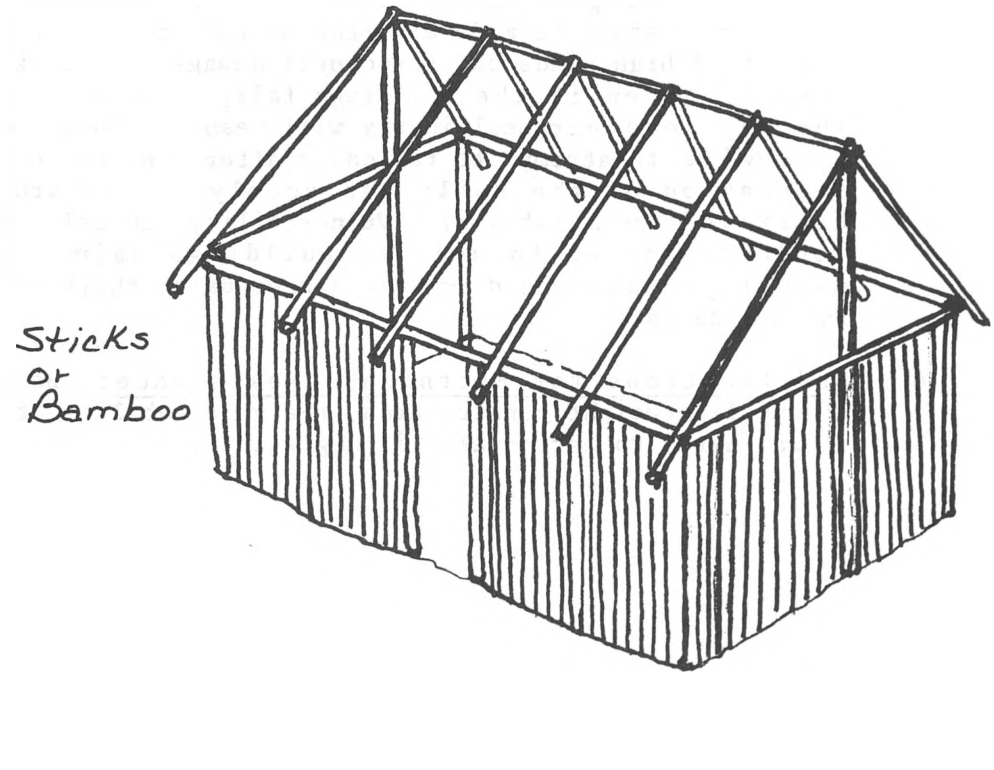
VULNERABILITY ANALYSIS OF THE BASIC CONSTRUCTION TYPES

A. Traditional Hares

Few traditional houses, or hares, are still found except on the more remote outer islands.



1. Construction: Traditional hares are made in a variety of ways, and distinct designs are found on each island. A common method used on Mangaia is illustrated below.



Bamboo or small straight sticks are attached vertically between the posts to make the walls. These are often supported by small horizontal poles near the top of the wall that help to reinforce the walls. 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 hares, nails have replaced the binding.

2. Roof: Hares normally have a thatched roof made of palm leaves. Most roofs have a 35°-40° pitch and use a gable configuration slightly recessed at the top of the gable. In recent years, many thatched roofs have been replaced by corrugated iron (C.I.) sheets.

3. Size: Hares average about 12 x 30 feet.

4. Vulnerability: Two weak points of hares are the connections between the roof and wall posts, and deteriorated wall posts. The major weak point, however, is the walls which allow excessive amounts of air to enter the building during a storm. For this reason the buildings always receive major damage.

   Hares 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.

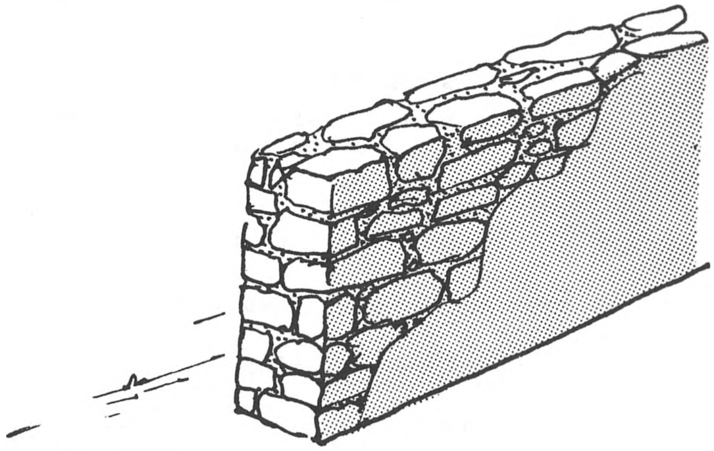
5. Modifications for Wind Resistance: The hurricane resistance potential for hares, even if properly built and reinforced, is poor. Structural performance can be improved although, due to the type of construction, the building cannot be made airtight or sufficiently strong to withstand high winds and structural damage can be expected. However, even if the buildings fail, it is very unlikely that serious personal injury will result. Thus, it would be unwise to attempt to radically alter the design or configuration of the buildings solely on the grounds of hurricane vulnerability. Vulnerability reduction efforts would be better focused on buildings using heavier materials that would be more dangerous to their occupants in hurricanes.

6. Modifications for Earthquake Resistance: Because of their lightweight construction, the vulnerability of traditional hares to earthquakes is negligible.

B. Coral-and-Lime Construction

Coral-and-lime houses date back to the 18th century and at one time were a very common form of housing. The process saw a brief revival in the 1950's, but no one is curently building with the technique. A few families still live in coral-and-lime buildings, but the number is decreasing each year.

1. Construction: There were several variations of wall construction. In the most popular, coral rocks were cemented vertically against a wooden panel. The panel served as a guide and helped align the wall as it was laid up. When a segment of the wall was completed, the wood panel was removed and repositioned for the next segment of construction. The process was repeated until the entire wall was completed. The walls normally rested on larger coral blocks, although some were situated on stone foundations.



The mortar was often made of burnt marl (deposits of clay and calcium carbonate burned to yield a mixture chiefly of lime). Sometimes fibers such as horsehair were added. More recently, lime-and-cement and cement-and-sand mortars were used. The cement-and-sand mortars have weathered well, but lime mortars show a good deal of deterioration.

2. Roof: Coral-and-lime houses today usually have C.I. sheet roofs. Both gabled and hipped configurations are seen.

3. Size: Houses built in this manner are small to medium in size, between 15-20 feet wide and 30-40 feet long.

4. Vulnerability: Coral-and-lime houses can be extensively damaged in hurricanes. Expected damage includes separation of the roof from the walls and failure of gables. Failure of the walls, however, would be rare as the buildings have

quite a bit of mass. Such failures would be a result of wind-driven rain eroding parts of the wall.

5. Other Weak Points: Louvered windows have been fitted to many coral-and-lime houses. In high winds, louvers allow excessive amounts of wind through the windows, thereby increasing the pressure which pushes upward on the roof, lifting it off the walls.

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

   a. Emergency measures

      --- Use more nails to fasten the zinc sheets to the roof trusses.

      --- Fasten the roof rafters to the ring beam with metal straps or hurricane fasteners, giving special attention to the corners.

      --- Seal the eaves of the structure to reduce uplift under the overhang.

      --- Board up windows in a hurricane.

   b. Progressive upgrading measures

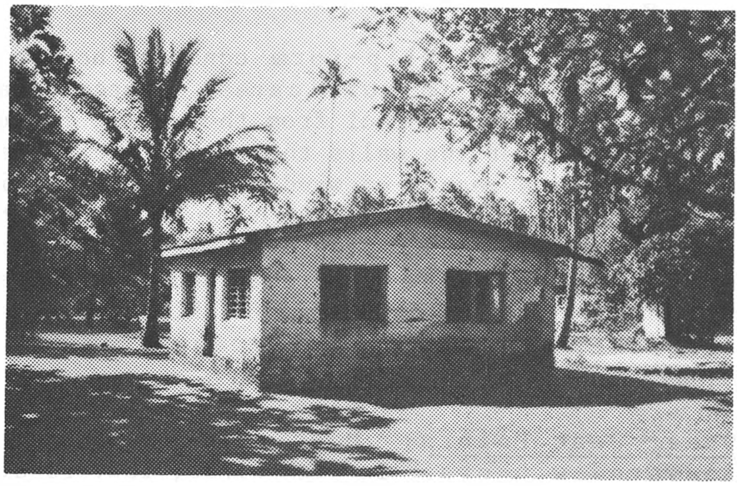
      --- Add storm shutters to help close off louvered windows during periods of high winds.

      --- Replace coral gables with wooden gables. In a hurricane, coral gables tend to break and could fall into the house.

   If the above recommendations are carried out, the wind resistance potential of coral-and-lime structures will be increased. If properly maintained, this type of building will provide moderate wind resistance.

7. Modifications for Earthquake Resistance: Coral-and-lime structures have demonstrated poor resistance to earthquakes. The most important modification that could be made to existing buildings would be to place pilasters or buttresses in the corners and along the walls, but earthquake risk is not high enough to justify such an investment.

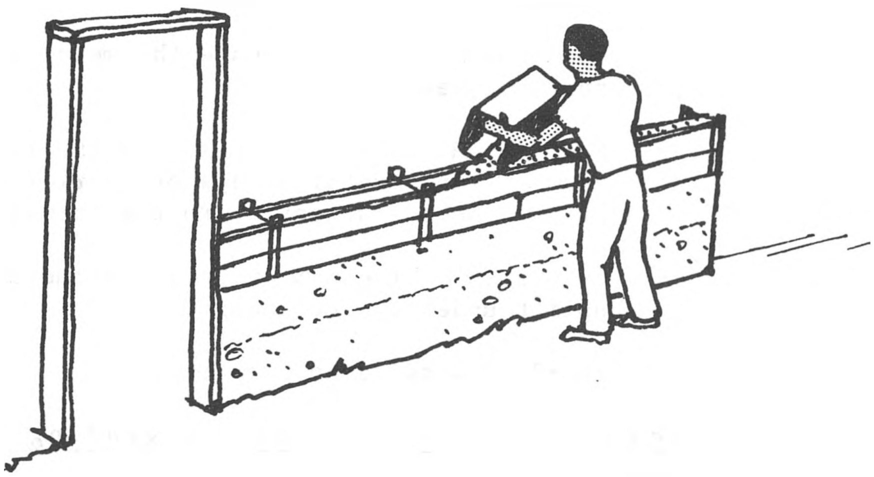
C. Slip-form Concrete



1. Construction: Slip-form concrete walls are built by erecting a wooden form, placing the sides 12"-18" apart. Concrete is then poured between the formwork. As soon as the concrete is set, the form is moved to another part of the wall and the process is repeated until the entire wall is completed.

   The wall is usually reinforced with steel rods. In some cases wire is tied between the iron reinforcing rods.

   Foundations for most slip-form concrete houses are made of coral, rocks or stone cemented into place.



2. Roof: Slip-form concrete houses usually have C.I. sheet roofs. Both gabled and hipped configurations are used.

3. Size: Houses built in this manner are of moderate size, averaging between 15-25 feet wide and 35-50 feet long.

4. Vulnerability: Slip-form concrete houses can be extensively damaged in hurricanes. Expected damage includes separation of the roof from the walls, failure of gables, and failure of the walls themselves. Failure of the walls is usually a result of wind-driven rain eroding the poorly made concrete walls. Even those houses that have iron rebars suffer this type of damage because the steel only serves to bond the concrete, not to provide load-bearing strength. Studies of damage to this type of structure show that there is a high percentage of walls toppling en masse.

5. Other Weak Points: Most slip-form concrete houses have louvered windows. In high winds, louvers allow excessive amounts of wind through the windows, thereby increasing the likelihood that the roof will blow off.

   Other weak points of the structure include the connection between the roof frame or truss and the wooden ring beam atop the wall.

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

   a. Emergency measures

      --- Improve the connections between rafters and ridge pole and at top sill plate.

      --- Use more nails to secure the metal sheets to the roof trusses.

      --- Fasten the roof rafters to the ring beam with angle irons, metal straps or hurricane fasteners, giving special attention to the corners.

      --- Close off the eaves of the structure to reduce uplift under the overhang.

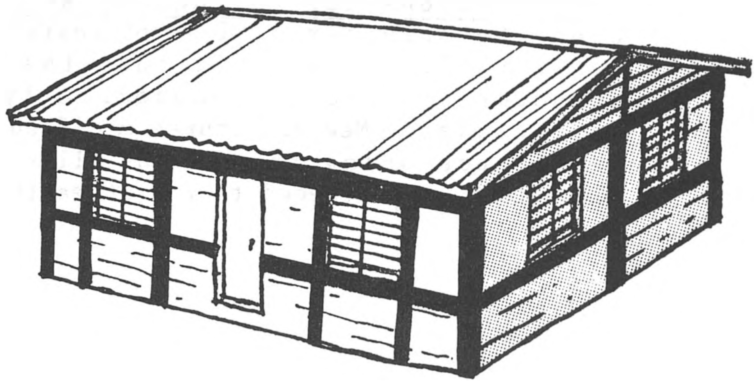
      --- Board up windows in high winds.

   b. Measures for progressive upgrading and/or new construction

      --- Use a hipped roof configuration.

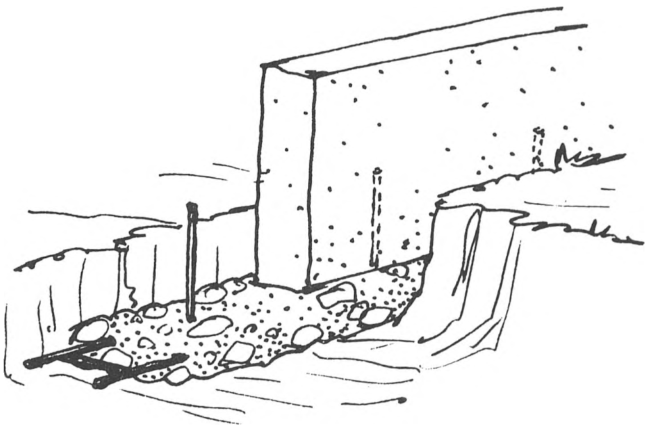
      --- Add storm shutters to help close off louvered windows during periods of high winds.

--- Pour a concrete frame, using iron rebars for reinforcing. The frame should consist of corner posts, center posts, and a ring beam.



--- Place a wood beam on top of the wall and attach it by bending steel rebars imbedded in the wall onto the frame. Then attach the roof trusses to the wood with hurricane fasteners or straps.

--- Place each wall on a solid concrete and stone foundation and tie the wall to it with steel bars buried in the concrete.



--- Use diagonal bracing in the roof structure of gabled roofs (see Chap. IV, Common Problems: Roof Configurations).

--- Replace concrete gables with wooden gables. In a hurricane, the concrete would tend to break and could fall into the house.

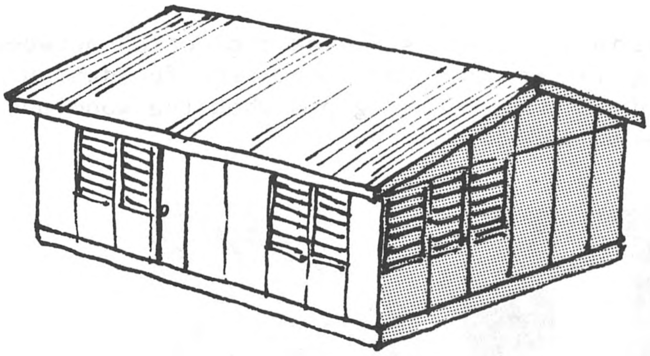
If the above recommendations are carried out, the wind resistance potential of slip-form concrete structures will be substantially increased. If properly reinforced, this type of structure can be made moderately wind resistant.

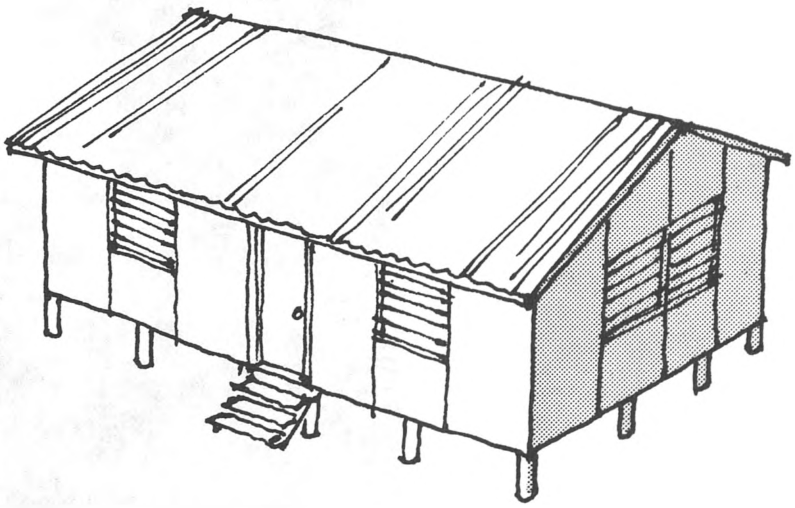
7. Modifications for Earthquake Resistance: Slip-form concrete structures will not resist earthquakes unless a concrete frame is built into the structure. Existing structures cannot be economically modified to resist earthquakes. New structures modified to improve hurricane resistance using the methods illustrated above should be adequately strengthened to resist earthquakes.

D. Wood Panel Construction

Wood panel houses are increasingly popular in the Cook Islands. Popularity may increase if economically attractive timber from Fiji becomes more available in the mid 1980's. The houses offer the advantages of ease of construction, ease of adding additions and suitability to the climate. If properly maintained, they will last for many years.

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





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

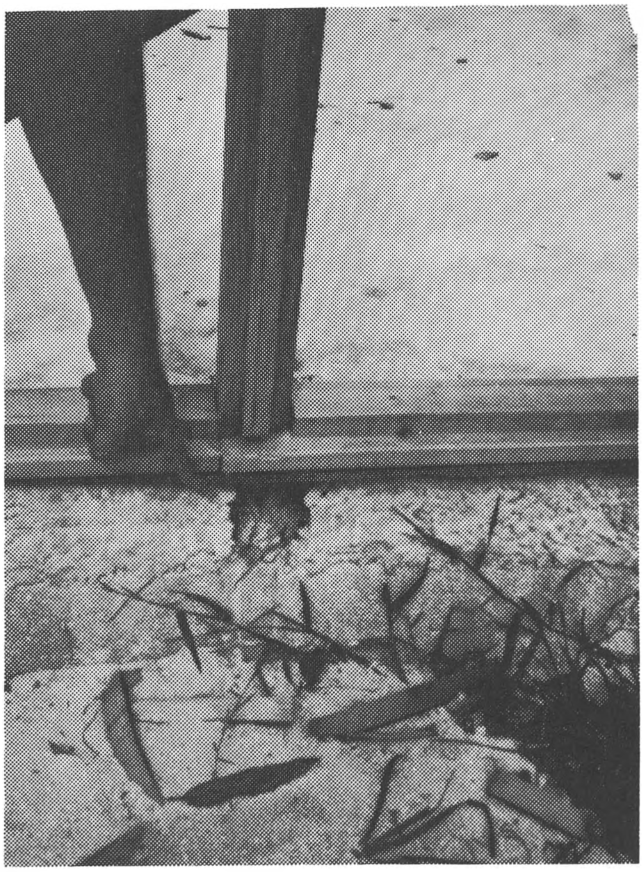
3. Size: Sizes vary from 12 x 15 feet to 20 x 50 feet.

4. Vulnerability: 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 panel houses rest on short piers or are anchored to the ground only by the corner posts of the frame. This is insufficient anchorage for hurricanes, and the houses may be lifted off the ground and toppled over.

5. Other Weak Points: Typical weak points of wood panel houses are the connections between roof sheeting and roof trusses (most nails are too short), the connections between roof trusses and walls, and the connections between the building and its foundation.

   The photo below illustrates a weak connection between the wood building frame and the concrete foundation. The cement failed at the holding pin when the wood post was nailed onto the horizontal piece.



6. Modifications for Wind Resistance: The following actions are recommended in order to improve the structural performance of wood panel houses in high winds:

a. Emergency measures

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

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

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

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

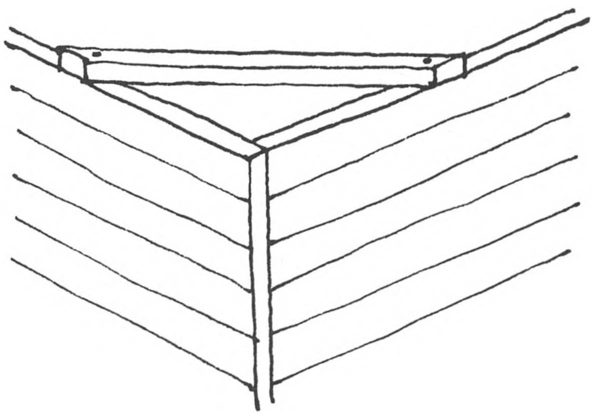
--- Board up windows during periods of high wind.

b. Measures for progressive upgrading and/or new construction

--- 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.



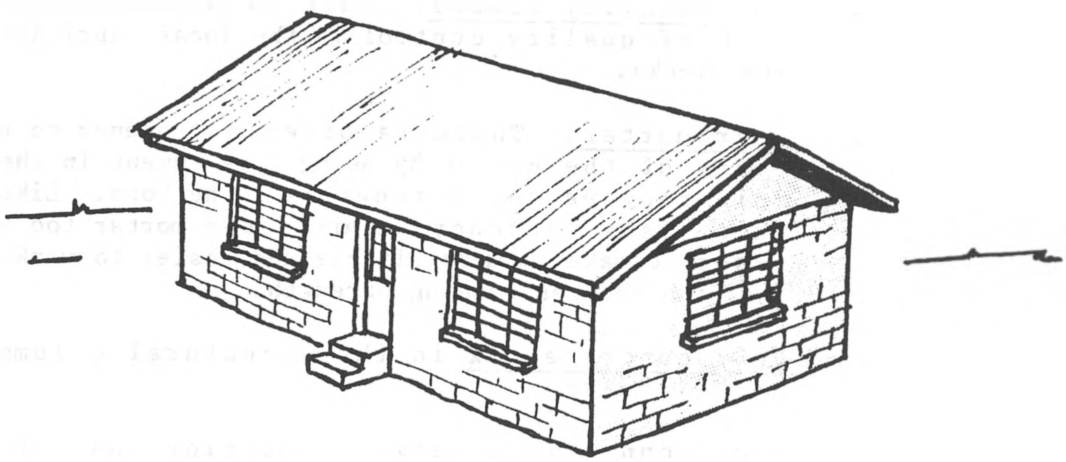
--- Anchor the structure securely. If piers are used, anchoring devices should be installed. If wood panels are bolted to the foundation, steel washers should be placed between the nut and the wood frame.

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

7. Modifications for Earthquake Resistance: The earthquake resistance of wood panel housing is very good and, by following the suggestions 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 between the piers and the building frame.

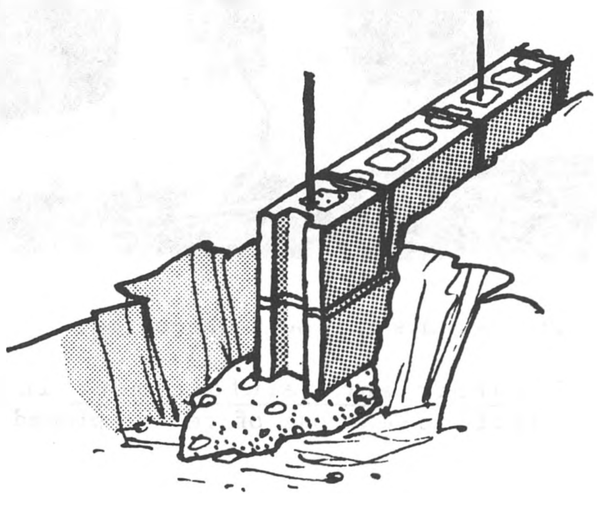
E. Concrete Block Construction

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 very dangerous.



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.

   In the Cook Islands, foundations are made by cementing a course of blocks slightly below ground on which the walls rest. This type of foundation is considered very weak and leads to differential settling, which in turn causes cracks which weaken the walls.



2. Problems in Masonry Construction: 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 in the Cook Islands, including:

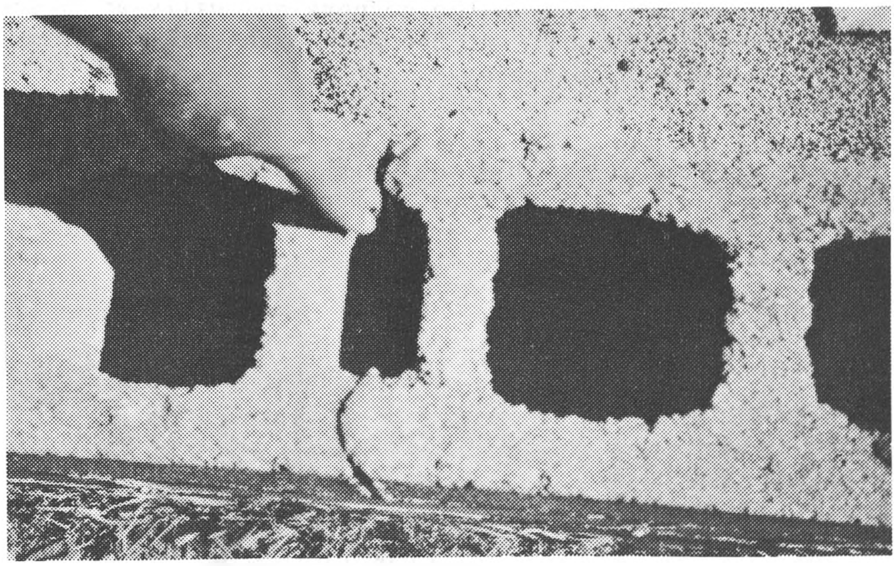
   a. Poor-quality blocks: This is usually a result of lack of quality control in the local fabrication of the blocks.

   b. Poor mortar: 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 bonding strength.

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

   d. Poor connections between interior and exterior walls. Usually the walls are only cemented together with butt joints rather than using interlocking masonry or tying the interior wall to the exterior wall with tie rods laid between the block courses.

   e. Insufficient mortar between blocks.



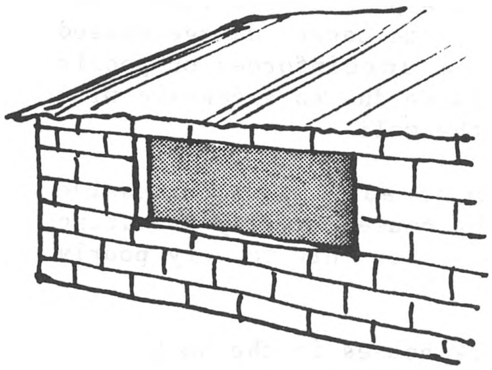
   f. Unlevel masonry on each course.

   g. Insufficient reinforcement in poured columns, and insufficient use of rebars placed inside block walls.

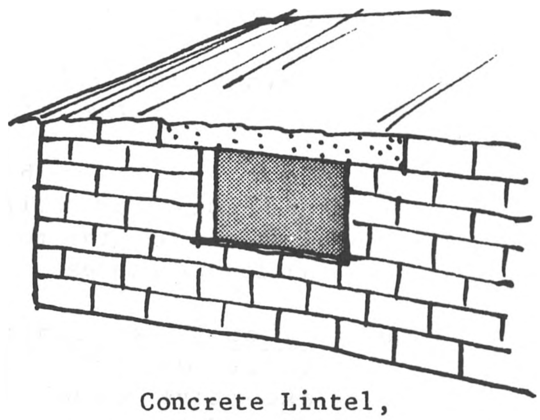
h. Poor detailing in corners. Many walls, for example, have no rebars at the corner or only one pin.

i. Improper or insufficient foundations.

j. Excessive spans and questionable detailing of lintels above windows.



Block Lintel,
Excessive Span

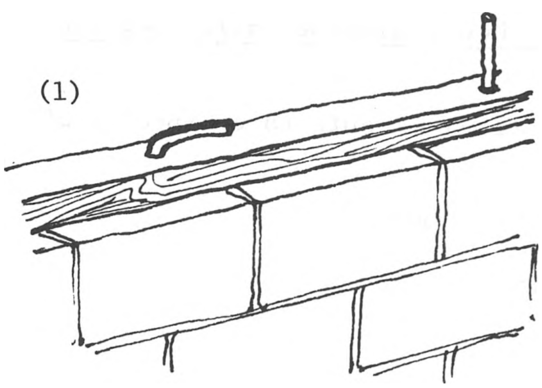


Concrete Lintel,
Proper Span

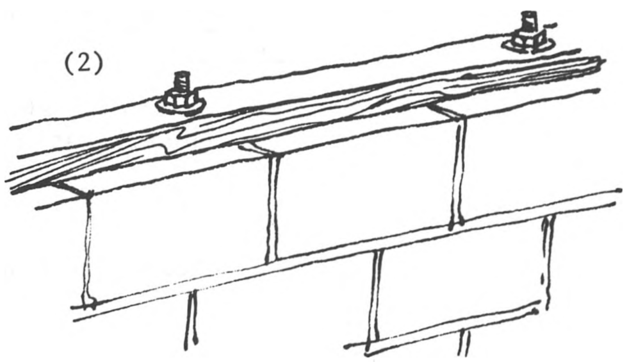
3. Roof: The roofs of most concrete block houses in the Cooks are covered with C.I. sheets. The sheets are attached to wood purlins which are fastened to trusses held on the walls in two ways. In the first, a portion of the steel rods used in the reinforcing columns is left protruding out of the ring 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.

(1)



(2)



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

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

5. Vulnerability: The principal damages to concrete block houses observed after recent hurricanes were 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.

6. Other Weak Points: Many block houses in the Cooks 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.

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

   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 hurricane fasteners or straps on each connection (see Appendix IV).

   b. Measures for progressive upgrading and/or new construction

      --- 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 these structures will be excellent and only minor damage should occur in windstorms.

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

V. VULNERABILITY REDUCTION STRATEGIES

Vulnerability reduction measures include three types of activities: emergency measures to protect existing buildings; progressive upgrading for existing buildings; and improved design and construction of new buildings. Due to the continuing high price of new construction and the difficulties of modifying existing buildings, priority should be given to emergency measures and to influencing the design and construction of new houses.

EMERGENCY MEASURES

Emergency measures are immediate actions taken to provide protection from an imminent danger such as a hurricane; they focus on actions to ensure people's safety. In the Cook Islands, actions to protect those living in traditional and transitional housing should be emphasized.

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.

The requirements for planning comprehensive emergency activities are:

A. Identification of emergency measures to protect buildings. This includes the measures that can be taken on short notice to save lives, protect buildings and reduce damage. Some emergency measures to protect buildings are illustrated in Appendix II.

B. Development of a plan to disseminate warnings and information. This includes a review of the activities required, the organizations that will participate, and the tools and equipment necessary, as well as formulation of a compre- hensive plan for dissemination of warnings.

C. Identification of public information requirments. A variety of media is required in order to disseminate the information thoroughly including leaflets, posters, prerecorded 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 if their houses are threatened by floods, storm surges or tsunamis, 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. While it is not necessary to prepare an elaborate plan (due to the small size of the islands), basic information must be prepared in advance and pre-positioned. In some cases, shelters for evacuees may be required, and they must be designated and strengthened in advance.

D. 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 must be acquainted with how to use the techniques.

E. 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 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 the Cooks, responsibility is shared among several ministries, but comprehensive preparedness measures have not yet been developed. Tonga's experience with Cyclone Isaac could provide some valuable lessons.

PROGRESSIVE UPGRADING

The overall objective of progressive upgrading is to strengthen existing housing to better 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. It should be emphasized that the majority of older and traditional buildings cannot be economically upgraded, so activities should concentrate on newer, more modern housing.

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 built-in anchoring devices.

The objective of upgrading is to reduce the need for replacement housing after a disaster. To encourage owners to upgrade their buildings, the measures should also improve livability and/or reduce costs of maintenance and operation.

Progressive upgrading requires a comprehensive approach and a strong, long-term commitment. The government should first develop a policy to guide the activities and an appropriate framework for implementation. In addition, a government agency should be designated 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 will help to identify the critical components and features of a disaster resistant building for each housing type.

   The New Zealand Building Code can be used for certain types of construction but enforcement beyond Rarotonga is minimal. Furthermore, transitional and traditional buildings are not covered and enforcement of the existing code on these types of buildings is not practical. For the purposes of providing safety, it is recommended that the New Zealand code be simplified and that basic minimal standards for safety be established.

2. Financial Assistance or Other Incentives. Some families will require financial assistance for upgrading their houses. The government should encourage lending institutions to expand existing loan programs to accommodate families wishing to improve their houses in accordance with the safety standards mentioned above.

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" should be devised and disseminated. This test would use a numerical grading system to help determine how safe the building is and 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. Many housing improvement measures and techniques will require the services of contractors. It is important that the government provide training to contractors to enable them to participate in housing improvement activities. A certification program for 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 houses should be assigned to a single agency. Possibilities include the Public Works Department or Department of Development Planning.

C. Financial Assistance: New approaches should be developed for the provision of financial assistance to homeowners for the upgrading of their homes. The financing institutions in the Cooks should be encouraged to develop special programs that would enable more people to participate. So that a greater number of people may 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 revised building standards. For persons unable to obtain these loans, alternative programs where they can obtain easy access to materials or small loans from other institutions should be developed.

D. Technical Assistance: Some provisions for making technical assistance available on a permanent basis should be established. One method that could be tried would be to train staff of the Public Works Department as building inspector/instructors to work with people building new housing and upgrading existing homes. The inspector/instructors would not only provide advice 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 helping them to obtain the appropriate financial and technical assistance required.

E. Technical Information Resources: At the present time, there is no single repository for information regarding low-cost housing or the techniques and skills required to maintain and upgrade housing. The government should establish small reference libraries on each island and designate personnel from Public Works to assist house-builders and demonstrate safe construction techniques.

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 should be established at Rarotonga. It is especially important that data be developed concerning historic and vernacular construction.

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 the development of a reservoir of talent and public information on how to build safely.

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

--- Changes in building configuration.

--- Changes in building layout.

--- Changes in roof configuration.

--- Changes in roof pitch.

--- Changes in balance (i.e. designing the buildings so that parallel walls are roughly equal in weight).

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

--- Modifying certain details to increase strength (e.g. wall connections, roof-to-wall connections, reinforcing and braces).

--- Changes in design of foundations and footings.

Construction improvements include:

--- Improved quality of workmanship. By simply improving detailing such as nailing, planing, squaring joints, etc., strength can be added to important components.

--- Improved use of building materials. Changing the manner in which materials are used, or using a certain component in another place, can improve a building.

--- Increased use of reinforcing materials and components.

--- Use of better-quality materials. Strength can often be increased by choosing materials with stronger or more durable properties. Cement and steel are two good examples.

--- 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 emphasis is on affecting construction before and during the building process.

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. In order 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 encourage local lending institutions to provide limited funds to these families.

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 panel buildings. Provision of technical assistance is especially important on the outer islands because there will be more self-help construction in these areas. In Rarotonga and the more advanced islands, special 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 panel buildings.

VI. RECOMMENDATIONS FOR COMPREHENSIVE VULNERABILITY REDUCTION

ACTIVITIES

The following activities should be carried out to initiate and coordinate vulnerability reduction:

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, Development Planning Office, Ministry of Economic Development, Development Bank and interested foreign agencies participating in development programs.

C. Revise and simplify the New Zealand Building Code and prepare minimum performance and safety standards for all types of low-cost housing.

D. Prepare a comprehensive set of instructional materials including 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 periodic workshops for housebuilders and contractors in all parts of the country. Training should stress both how to modify existing buildings and how to build safer new buildings.

FINANCIAL STRATEGIES

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, 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. 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.

The foregoing suggested activities and strategies for reducing the vulnerability of low-cost housing in the Cook Islands should encourage safer construction and establish better building methods as part of the normal building processes. If these recommendations are followed, future hurricanes and earthquakes will have a much reduced impact on the homes and lives of the people.

APPENDIX I:

RECOMMENDED TRAINING AIDS AND PROMOTIONAL MATERIALS

Four 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.

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 Improving Your House: Pamphlet to help families determine whether their houses can be economically improved and strengthened. The pamphlet should use a check-list and numerical grading system to help homeowners determine the relative safety of a building, and 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 Design and Construction of New Buildings

**4. Instructor's Manual: A manual containing sections on construction techniques, building details, instructional techniques and guidelines for training including how to

---

*Denotes materials already available

**Denotes materials that could be quickly adapted from similar training aids already available.

Except for materials denoted by an asterisk, all titles are descriptive only.

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.

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

**6. How to Build a Safe Wood Frame House: Pamphlet to serve as a guide for those building new wood frame houses.

**7. How to Build a Safe Concrete Block House: Pamphlet to serve as a guide for those building with concrete block.

**8. 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).

9. 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.

B. Training Aids for Upgrading Existing Buildings

**10. 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.

11. How to Strengthen Wood Panel 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.

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

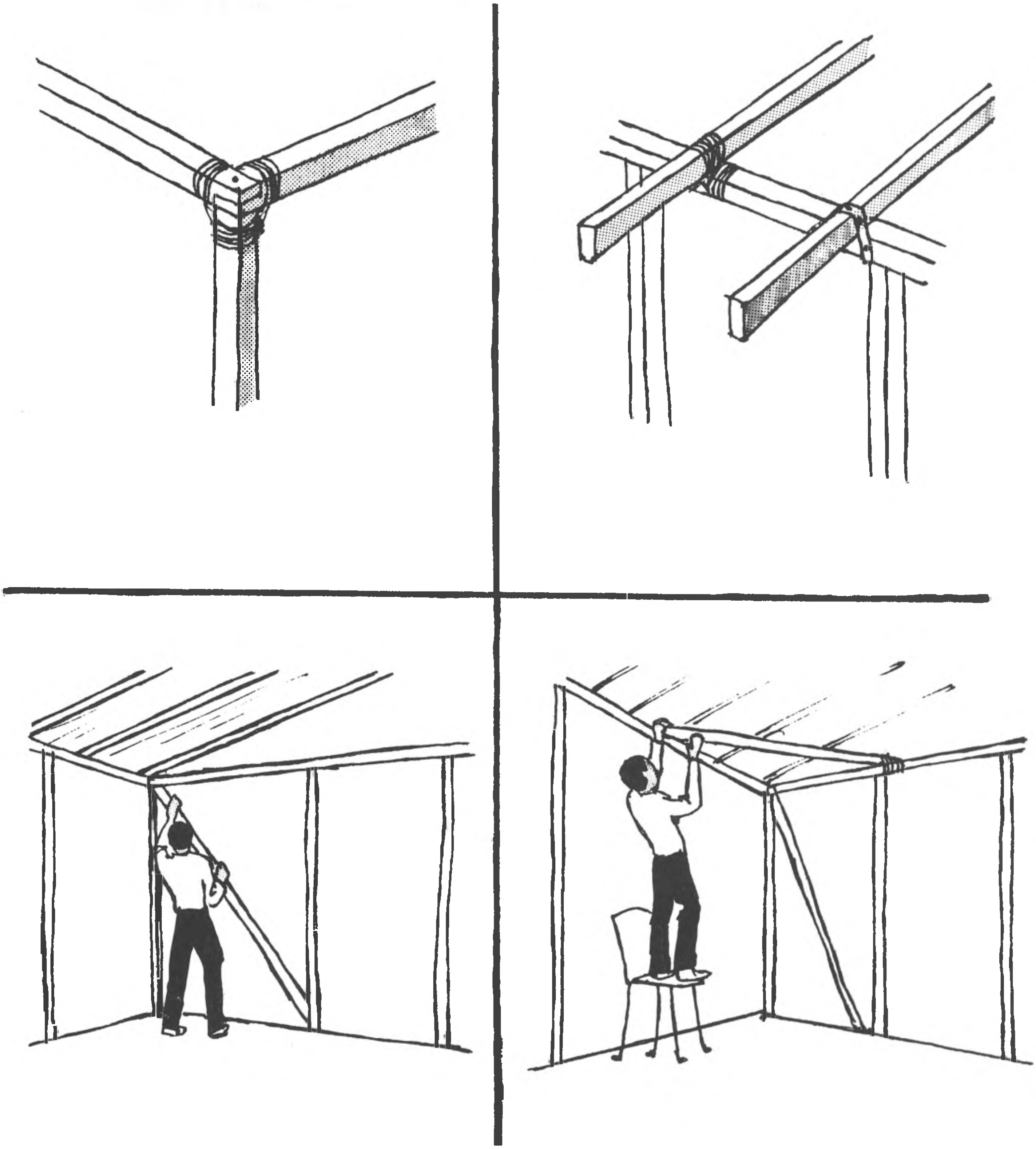
C. Instructional Materials for Emergency Protection of Existing Buildings

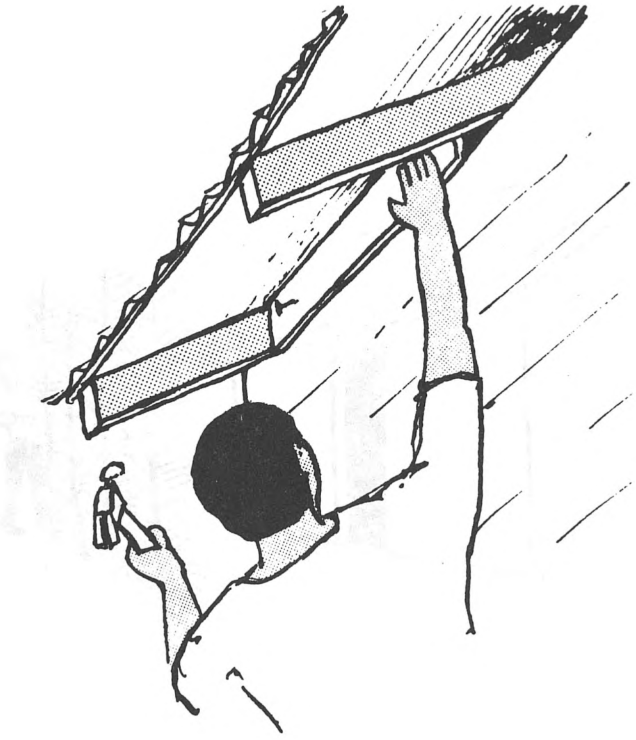
Many of the materials identified above can be used to provide homeowners with information on repairs, modifications or retrofits that can be carried out when a hurricane threatens.

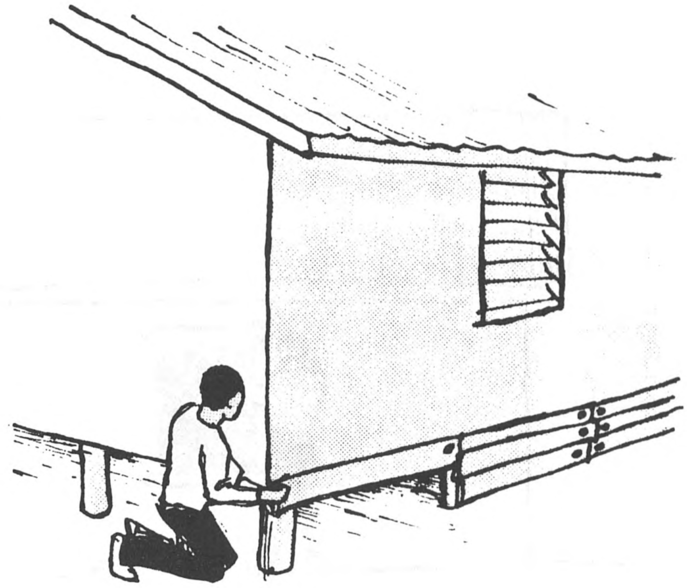
In addition, a special pamphlet entitled "How to Protect Your House in Hurricanes" should be developed. This would be a guide to simple improvements for all types of housing, and would provide information on how to protect the building and the site, and how to determine whether or not a family should evacuate to a safer area.

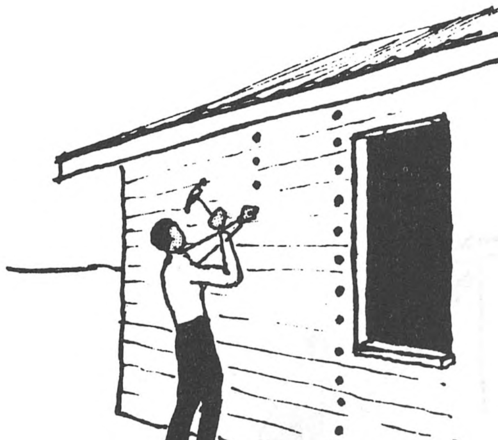
APPENDIX II

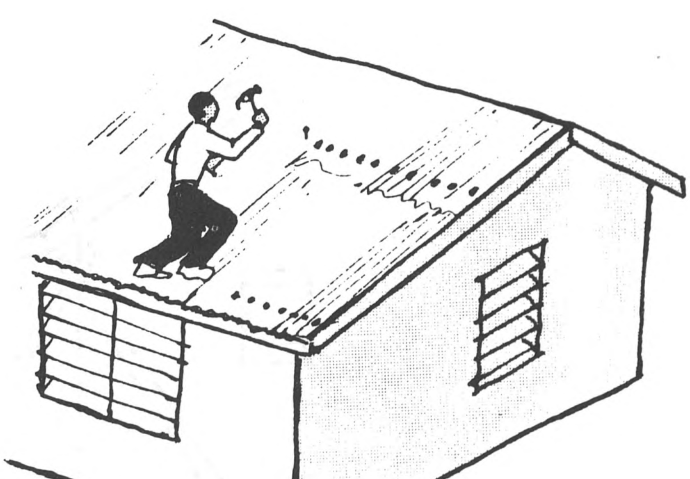
EMERGENCY MEASURES TO PROTECT SMALL BUILDINGS FROM HURRICANES

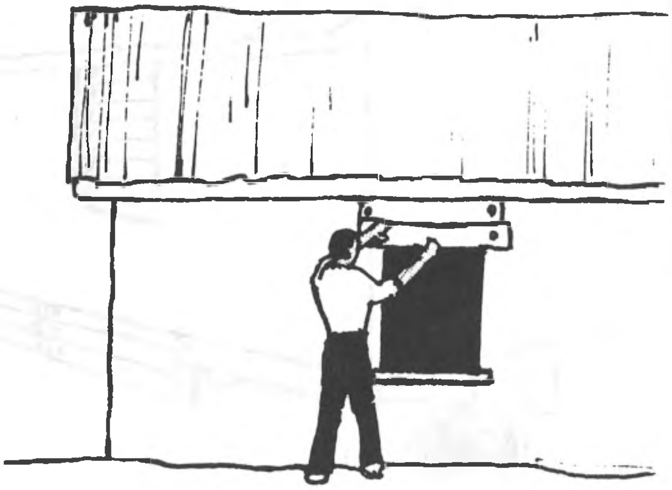


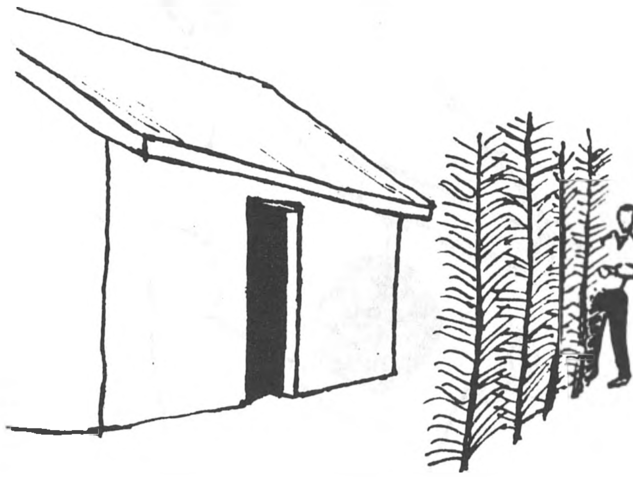


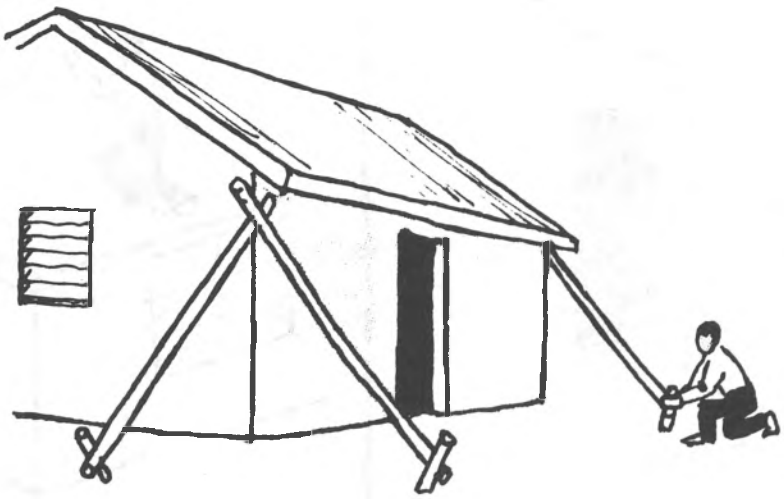


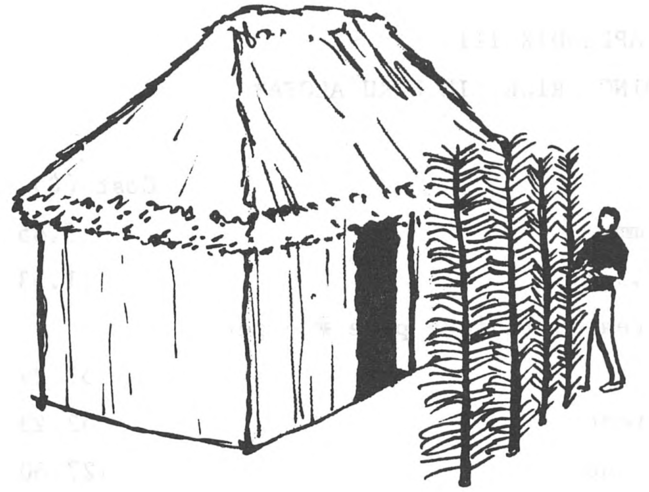


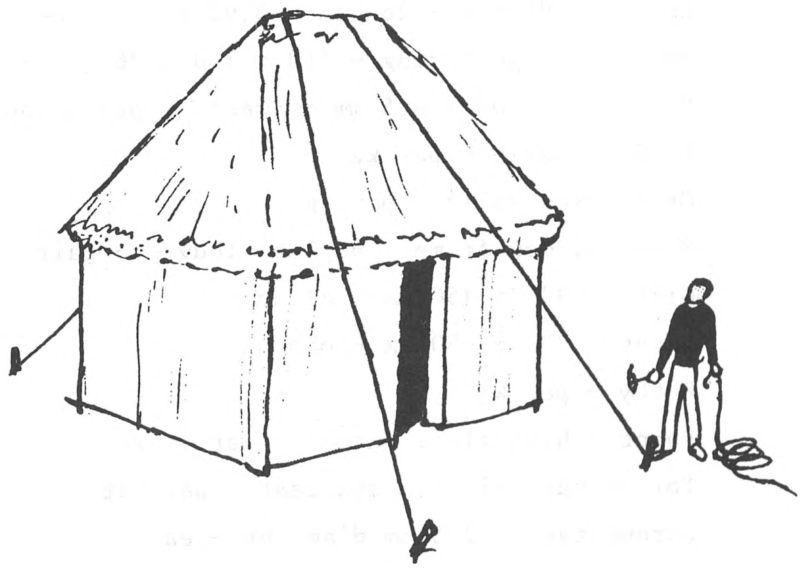


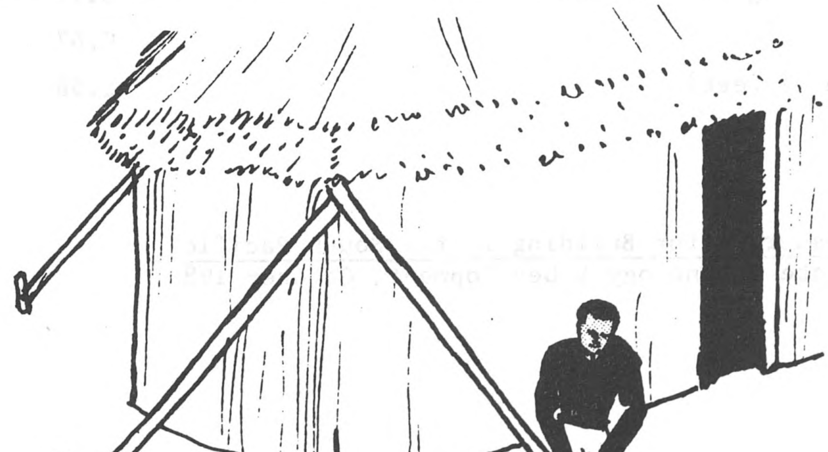












APPENDIX III:

CURRENT BUILDING PRICES IN NUKU'ALOFA*

Material Description	Cost ($)
Hardboard - 2400 x 1200 x 5 mm	5.45
Softboard - 2400 x 1200 x 12.5 mm	11.53
Timber - T&G floorboards - treated radiata pine # - per 100 superfeet	57.29
Other timber - per 100 superfeet	52.23
Cement - (40 kg bag) - per tonne	127.60
Concrete blocks - 450 x 225 x 150 mm	0.37
Crushed coral - ex quarry - per cubic metre	7.96
Sand (beach) - ex beach - per cubic metre	7.22
Corrugated iron - 26 gge x 0.92 m - per metre	3.24
Galvanised guttering - 150 x 150 x 26 gge - per metre	1.59
Mild steel rod - 9.5 mm diameter - per tonne	861.24
Roofing nails - per kg	2.57
Galvanised nails - per kg	1.53
Steel window frame - 6 plate louvre - pair	6.53
Glass - 900 x 150 mm - clear	1.33
Glass - 900 x 150 mm - obscure	1.65
Putty - per kg	1.12
Paint - high gloss enamel - per litre	5.50
Toilet pan, cistern and seat - per set	104.86
Chrome tap - 12.5 mm diameter - each	7.89
Galvanised water pipe - 12.5 mm diameter - per metre	2.05
Power point, switch plug combination	3.77
Light bulb - 60 watt clear	0.67
Tube light - 635 mm (2 feet)	2.58

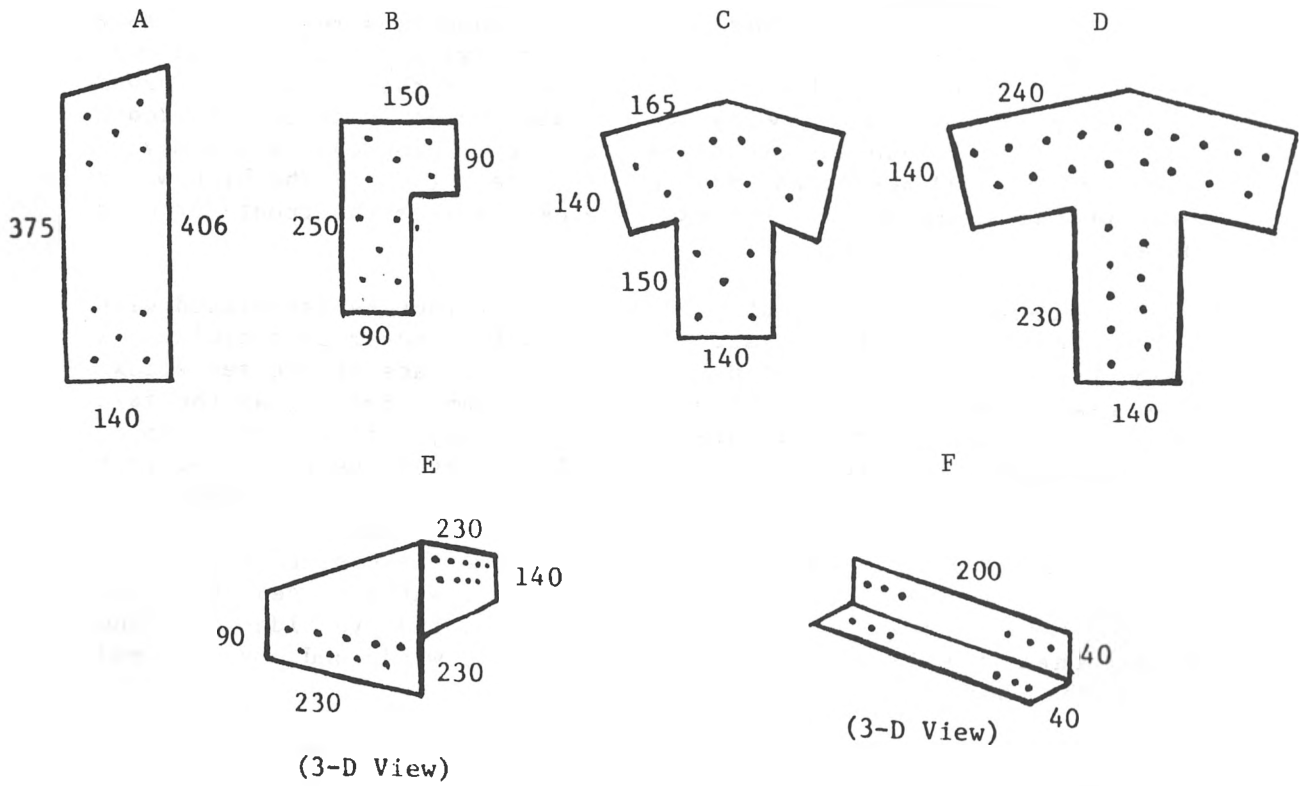
---

*From D.J. Cook, Resources for Building in the South Pacific, Centre for Appropriate Technology & Development, October 1980.

APPENDIX IV:

COMMERCIALLY AVAILABLE HURRICANE FASTENERS

The fasteners below are made of rigid galvanized steel and are specially designed for use in low-income houses. They are available from various suppliers in the region and from Ridout Industries in the U.S. All dimensions are in millimeters.



Types A - E are 4mm thick.
Type F is 2mm thick.
All angles are 15°, 75° or 90°.
All holes in brackets are 5mm in diameter.

Estimated quantities required per house:

	A	B	C	D	E	F	Nails
Moderate-sized house with solid floor	4	8	2	1	2	30	400
Small house with earthen floor	4	8	-	-	2	31	350

APPENDIX V:

PROTECTION OF SETTLEMENTS ON ATOLLS FROM STORM SURGES:

A CASE STUDY OF PALMERSTON ISLAND

STORM SURGES

A storm surge is a rapid rise in the level of the sea which is caused by a cyclonic storm. Although sometimes referred to as a tidal wave, a storm surge is not actually a wave; it is a large mass of water which rises above the normal level of the sea and is pushed along by the storm, moving in the same direction as the hurricane system. This movement creates a front or leading edge which may be many miles (kms) across and as high as 65 feet (20m). The high water behind the leading edge may extend backward from the front for many miles.

A storm surge is created by a number of factors associated with a hurricane. First, the air pressure in the center of a cyclone is very low. This release of pressure on the surface of the sea allows the sea to expand and rise upward in a hump. Second, as the fast winds of a hurricane move over the water, they pile the water up as the hurricane moves toward the coast. Large waves are pushed against the shore but cannot retreat from the coastline rapidly because the winds slow their return into the sea. This problem is made more severe if the sea bed is shallow. By the time the center (or eye) of the hurricane arrives, the large mass of water raised above the normal level of the sea by the low pressure at the eye rides over the water that has been piled up by cyclonic winds and moves inland across the shore in one rapid surge.

Every hurricane has a storm surge. Many are small, but a few are very large. Many different factors determine how big a storm surge is, how far it moves inland, and how much damage it does.

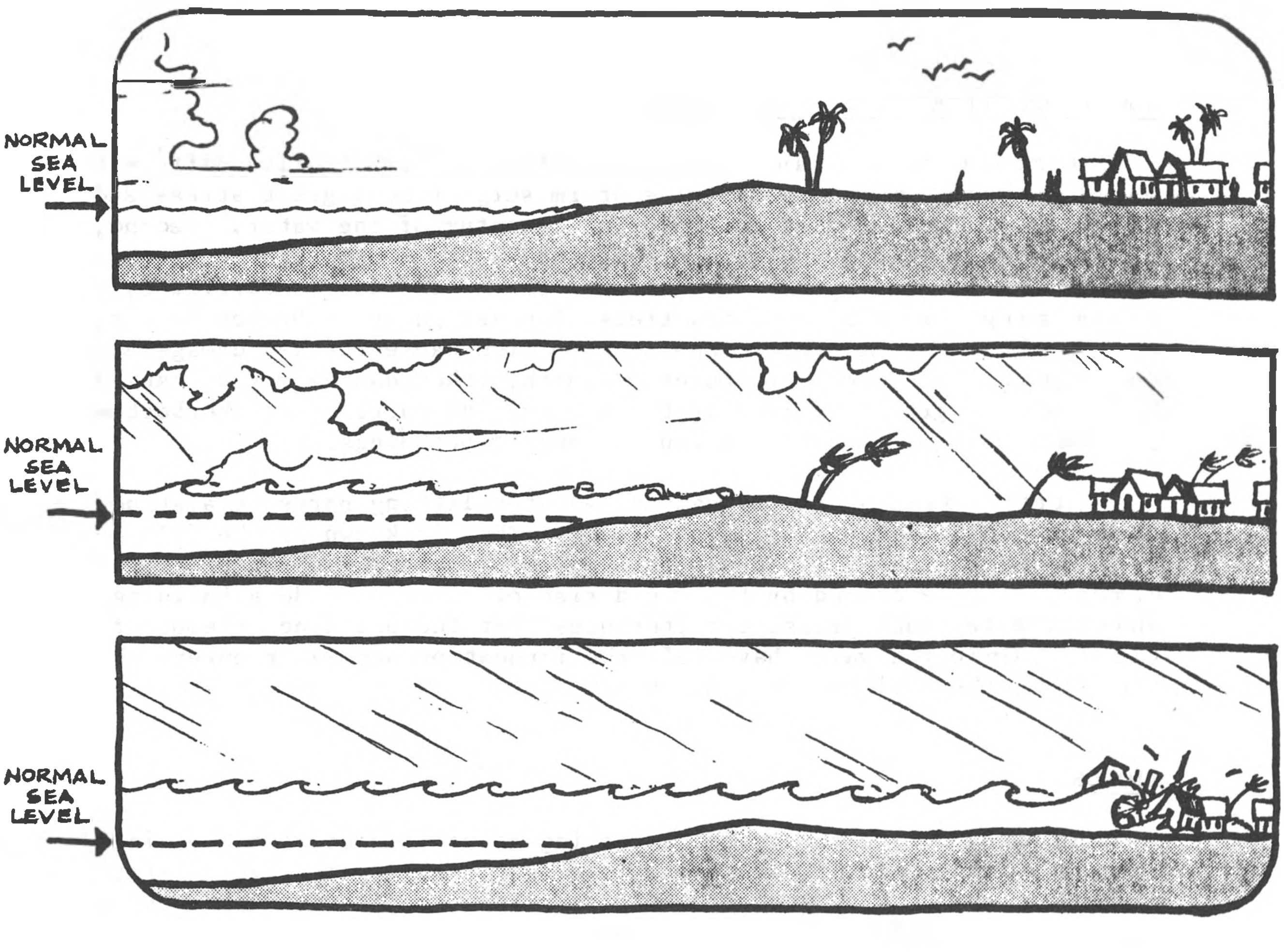
The drawing on the next page shows what a typical storm surge looks like in cross-section. While the leading edge of a storm surge appears to someone standing in its path as a wave, it must be remembered that it is in fact a rapid rise in sea level, and everything in its path will be submerged for a long period of time after the leading edge has passed.

There are five factors which determine the height of a storm surge:

--- the air pressure at the center of the storm;
--- the speed of the hurricane;
--- the speed of the winds in the hurricane;
--- the height of a normal tide.

Of these factors, the height of the normal tide is one of the most important to consider. For example, the low pressure at the center of the storm may raise the level of the sea 20 feet (6m). The winds which pile up the water usually add another five feet (1.5m). The speed of the hurricane usually adds another 5-10 feet (1.5-3m). If the storm surge arrives at the coastline at the low tide period, then the height of the wave will be reduced by an amount equal to the difference between normal sea level and low tide. In other words, if low tide is ten feet (3m) below sea level, then the height of the storm surge will be reduced by ten feet (3m).

However, if a storm surge arrives at high tide, then the height of the storm surge will be increased by the height of the tide above normal sea level. Thus, if the normal high tide is ten feet (3m) above sea level, that ten feet (3m) will be added to the height of the storm surge.



A storm surge will move inland until it reaches a point where the ground is as high above sea level as the top of the storm surge. In other words, if a storm surge is 9 feet (3m) high, it will continue to move inland until it reaches a point where the land is 9 feet (3m) above sea level. The wave crashes when it reaches an area where the water depth becomes too shallow for the wave-like motion of the leading edge to continue. The water that continues inland can still cause damage and carries much underwater turbulence. On a small, low island or atoll the momentum of the surge and high winds of the hurricane may propel the water completely over some islands.

Once a storm surge has stopped moving forward, the water will begin to retreat to the sea. However, on the surface of the water, new waves may be created by the action of the high winds associated with a hurricane. All the water will not leave until the eye of the hurricane has passed and the winds begin to subside as the hurricane moves inland. The actual storm surge itself may inundate an area for as long as 45 minutes.

HOW STORM SURGES DAMAGE BUILDINGS

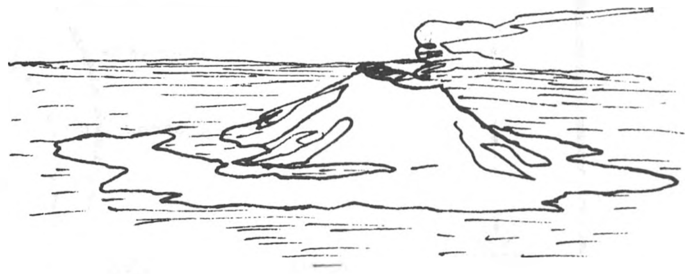
A storm surge can damage or destroy a house in five different ways. First, the speed of the storm surge places great stress and force on the walls, just by the great momentum of the water. Second, the currents and turbulence associated with a storm surge destroy a structure by eroding the foundation. Third, the debris carried by a storm surge (such as uprooted trees, fences, parts of broken houses, etc.) will act as battering rams which cause further damage and destruction to other structures. Fourth, other damage may be caused by sand and gravel carried by the fast-moving currents at the bottom of a storm surge, eroding the foundations of buildings.

Fifth, damage can be caused by water lifting parts of a structure up to float on top of the surge. This is known as the "flotation effect" and it can happen even to buildings made of brick and cement. It is caused by the rapid rise of water outside a building, which creates such pressure differences that the building attempts to float. Once the walls have left the foundation and water enters the structure, the building will collapse.

ATOLLS

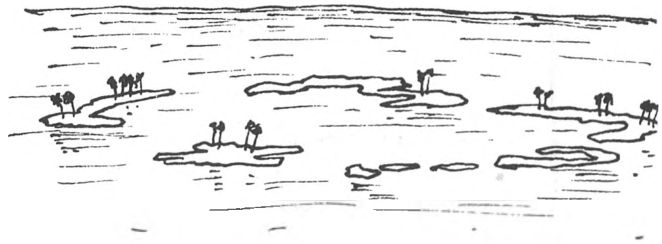
An atoll is a coral reef appearing above the sea as a low ring-shaped coral island or as a chain of closely-spaced coral islets around a shallow lagoon that may vary in diameter from less than a mile (1.4 km) to 80 miles (120 km) or more.

1



2

3

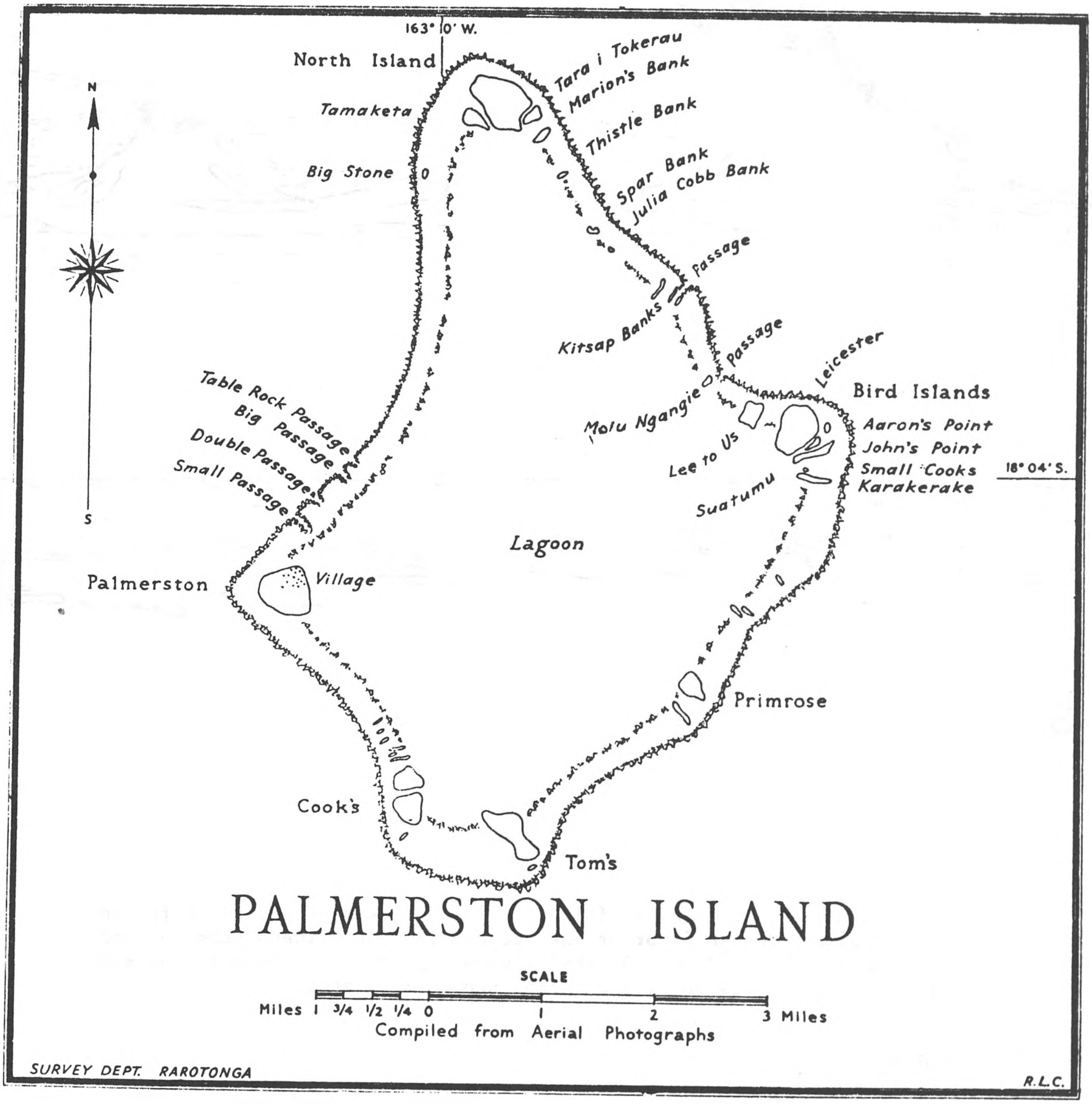


4

Atolls are formed as follows: 1) a volcano erupts and a fringe reef forms; 2) the floor of the ocean below the volcano subsides and a ring reef develops; 3) the volcano top erodes to form island and reef; 4) final erosion of the island produces an atoll.

PALMERSTON ISLAND

Palmerston Island is a coral atoll of the Cook Islands and is located 270 miles northwest of Rarotonga. The island consists of a ring of small islets within a fringing reef. The largest islet and the only one supporting a permanent settlement is Palmerston, after which the island is named.



163° 0' W.
North Island
Tara i Tokerau
Marion's Bank
Tamaketa
Thistle Bank
Big Stone
Spar Bank
Julia Cobb Bank
Passage
Kitsap Banks
Passage
Leicester
Bird Islands
Table Rock Passage
Big Passage
Double Passage
Small Passage
Molu Ngangie
Lee to Us
Aaron's Point
John's Point
Small Cooks
Karakerake
18° 04' S.
Suatumu
N
S
Lagoon
Palmerston
Village
Primrose
Cook's
Tom's
PALMERSTON ISLAND
SCALE
Miles 1 3/4 1/2 1/4 0 1 2 3 Miles
Compiled from Aerial Photographs
SURVEY DEPT. RAROTONGA
R.L.C.

The highest point on the island is just 11 feet (3.5 metres), making it particularly susceptible to high waves and strong winds. The economy is primarily subsistence-based. However, through the Cook Islands Government's development programs, copra production and commercial fishing are now gaining significant importance. The island has a population of approximately 65 permanent inhabitants.

Palmerston Island lies in the South Pacific hurricane belt and over the years has suffered severe devastation, but only one life has been lost in recent times. Hurricane damage is often severe, and total devastation of crops and buildings on the island has occurred several times in recent history.

The frequency of hurricanes affecting Palmerston is shown below:

Hurricane Frequency: Palmerston Island

Year		Description
1943		Severe
1963	- January	Minor
	- Mid-January	Moderate
	- March	Severe
1967		Severe
1970		Moderate
1974		Severe
1978		Severe
1980		Moderate

REVIEW OF APPROACHES FOR MITIGATING THE EFFECTS OF STORM SURGES

The following approaches have been used or proposed for protection of people from storm surges:

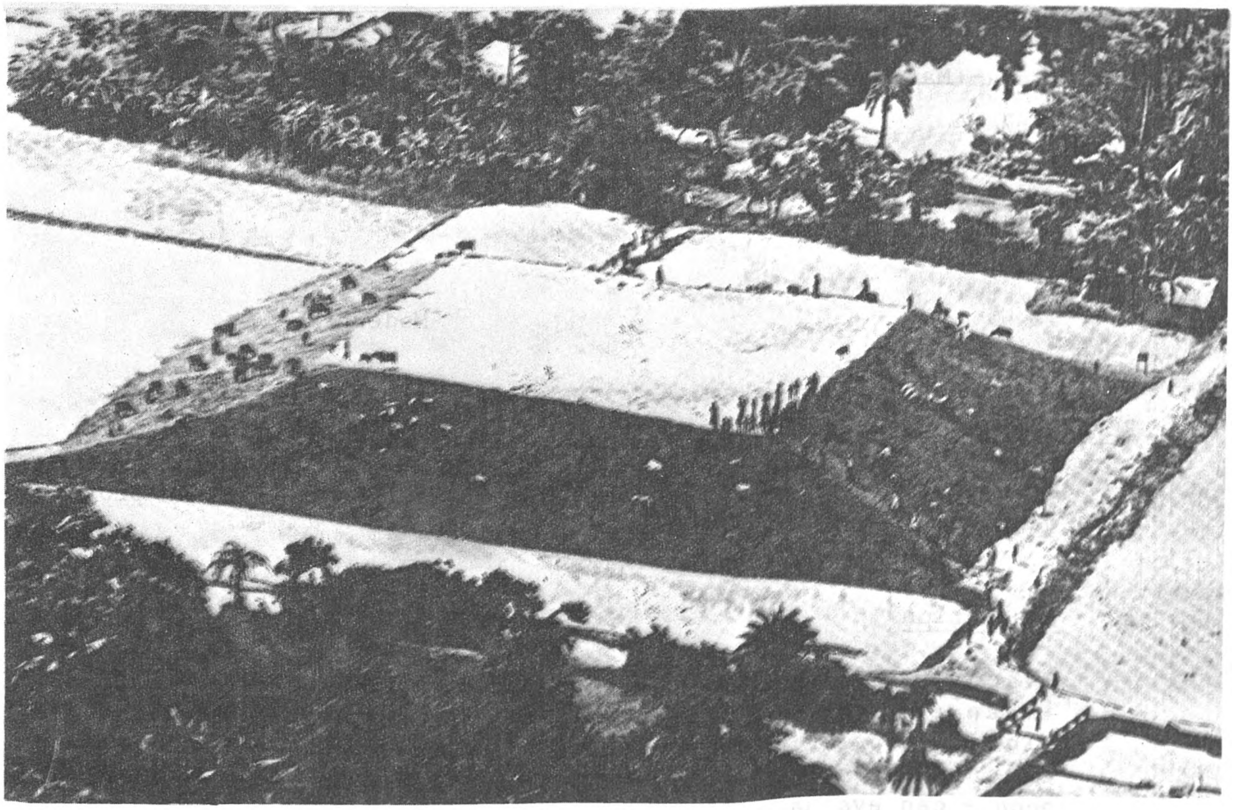
A. Evacuation

Evacuating people in highly vulnerable areas to safer locations is an often-used approach for saving lives. It requires considerable prior planning and coordination of warning systems and evacuation plans. It also requires a safe location to which people can evacuate.

Currently in the Palmerston Islands, when a severe hurricane strikes, the entire population seeks refuge within a clump of trees on the highest part of the island. This is satisfactory only for moderate hurricanes and storm surges. Evacuation off the island by ship would not be feasible because of the long distances between Palmerston and islands where ships may be located. Evacuation by air is also not feasible as there is no airstrip on the island, and the bay would most likely be too rough for seaplane landings during a storm.

B. Escape Mounds

Escape mounds are sometimes proposed as a solution for areas which do not have safe evacuation sites. Escape mounds are essentially mounds of earth that are constructed using excavated or dredged earth (see illustration below). The height of a mound is determined by estimating the height of a maximum storm surge plus 50% to ensure against overtopping by waves. The horizontal area on top is calculated at approximately 200 square feet (3.5 m^2) per person.



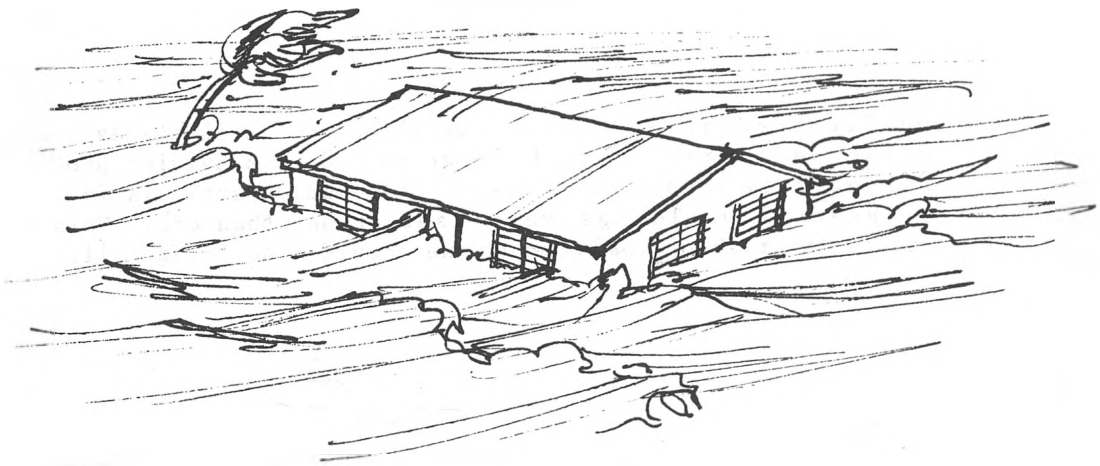
(Earth mounds, Bangladesh. Photo: League of Red Cross Societies/J. Mohr)

For Palmerston Island, an escape mound would be difficult and expensive to build. Heavy digging machinery would need to be shipped in, and it is unlikely that sufficient earth could be excavated from the atoll surfaces; dredging from the ocean would also be difficult as the coral reefs drop off very quickly. Furthermore, even if the escape mound could be built, it would take up an excessive portion of the small amount of surface area available to the inhabitants.

C. Strengthened Buildings

Strengthening buildings is accomplished by retrofitting existing buildings (adding braces, making walls heavier, adding reinforced concrete, etc.) or by incorporating design changes and improved construction methods in new buildings (see main report).

Strengthening buildings reduces structural damage to buildings by strong winds, but a building can still fail because of the force of waves or debris carried by storm surges. Furthermore, strengthening buildings will not prevent flooding and provides no protection against drowning.

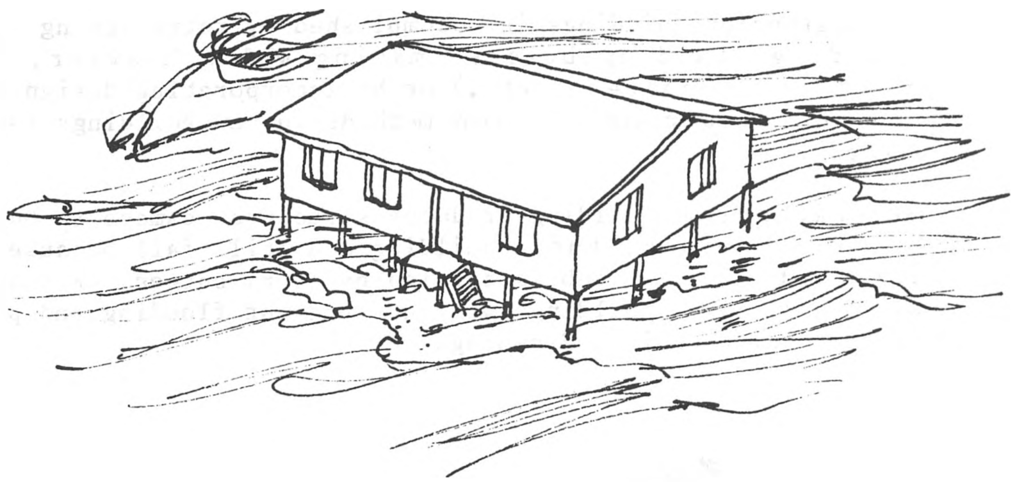


On Palmerston, because of the small size of the island and the danger that a massive storm would overtop the entire island, strengthened buildings would not guarantee personal safety.

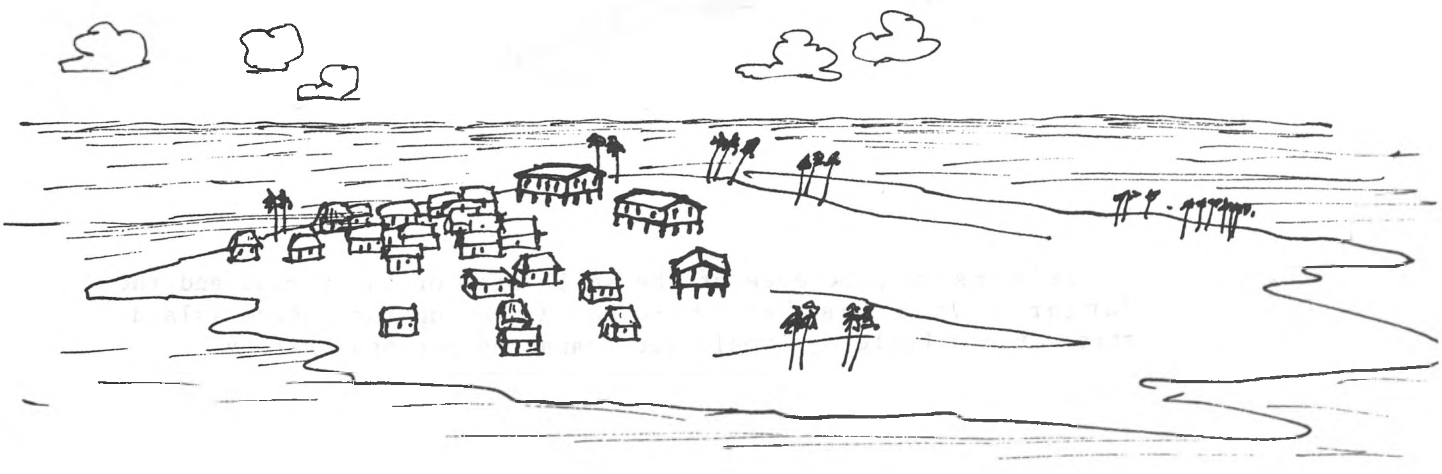
D. <u>Building on Piers</u>

Sometimes buildings are raised above the ground by placing them on posts or piers. If the buildings are well-constructed and the piers are strong and well-braced, they provide protection against most surges because the water can flow underneath.

A disadvantage is that buildings on piers are more vulnerable to high winds. Both buildings and piers must be specially braced and strengthened.

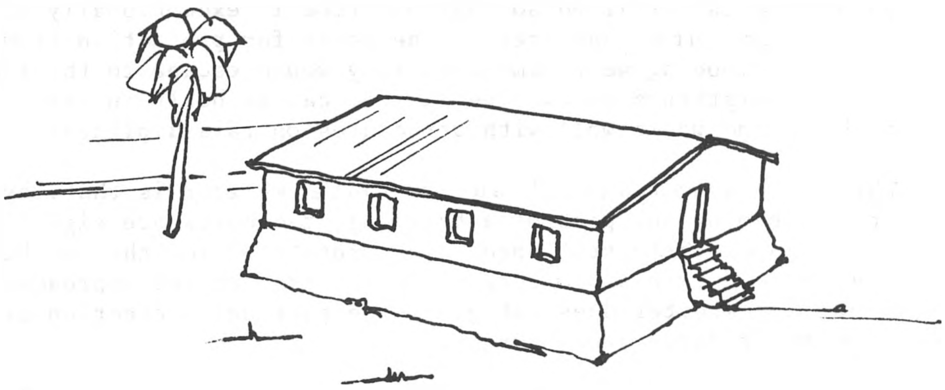


On Palmerston, erecting several raised buildings as shelters might be a relatively low-cost method of providing protection for average or smaller surges. This would particularly be true if several buildings were used rather than one. This would reduce the risk of losing everyone should a building fail.



E. Building on Plinths

Placing buildings on plinths made with stabilized earth, coral or concrete, or a foundation which has been raised, is another means of protecting the structure. These buildings provide some protection against localized flooding and smaller surges, and the more stable building is better able to resist high winds.



The disadvantage is that the plinth may induce water runup and, unless the plinth is very well-built, this may lead to settling problems that could damage the building. These buildings still have the problems of damage from water impact, debris impact and scouring.

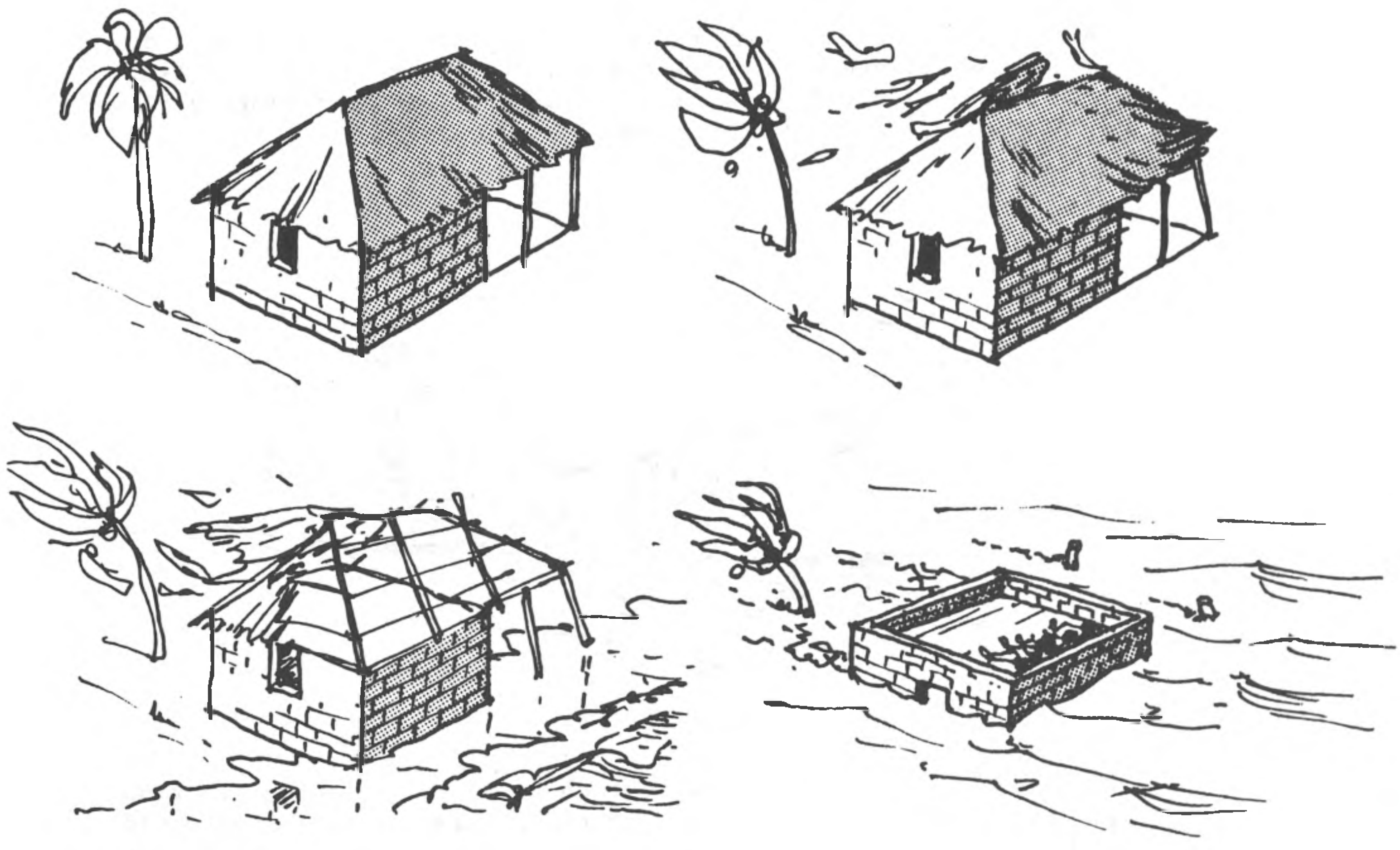
On Palmerston, houses on plinths should provide some protection against smaller surges. Retrofitting existing buildings would be difficult and expensive, but plinths could easily be incorporated into new construction.

F. In-House Shelters

An in-house shelter is part of a normal building designed in such a way that one portion or area of the house is strengthened to provide a sanctuary or escape area. In some cases, the building is designed so that one room is exceptionally strong. People go into that area of the house for protection from wind and, if flooding were imminent, they would escape to the roof of the strengthened room. The shelter can be built in any kind of building and works well with structures on raised plinths.

The main advantage of an in-house shelter is that, by only strengthening one part of a building, the costs are significantly reduced while still providing protection for the inhabitants against moderate storm surges. As in the earlier approaches, an in-house shelter does not guarantee personal protection against drowning in large storm surges.

This approach would seem workable for Palmerston, especially in new construction. It would provide a reasonable measure of protection at a low cost.



G. Community Storm Shelters

Community storm shelters (or hurricane shelters) are large buildings intended to provide shelter for families living in structurally unsound buildings threatened by high winds or storm surges. The shelters are usually buildings such as churches, schools, government buildings, community meeting halls, and/or large commercial structures (e.g., warehouses). Some are built as shelters and then given to the community to determine their use between emergencies.

Large buildings are more unstable than smaller buildings in hurricanes, and survivability in the collapse of a large building is far less likely than in the failure of a small dwelling. Furthermore, in flood-prone areas, casualty rates in large buildings used as shelters have been extremely high. Reports from several recent disasters indicate that deaths attributed to building collapse or inundation are far higher in large buildings than in houses. It is important to reiterate that <u>no</u> building can be guaranteed hurricane-proof.

For Palmerston, building a community shelter would be very expensive. A bigger concern is that, since the population is so small, the risk exists of losing the entire population if one community shelter, designed to protect everyone, should collapse or if a storm surge should flood the building and lead to the drowning of the occupants.

H. Recommended Approach

The best approach for protecting people is usually to diversify and try several different options. Palmerston Island should consider a combination of in-house shelters, building on piers, building on plinths, and strengthening buildings as the best long-term strategy for reducing vulnerability. By having several buildings that provide moderate protection scattered throughout the island, the risk could be spread. Since no one building can guarantee the safety of all the inhabitants, then the loss of any one building will only endanger the lives of a relatively small number of people.

This strategy is also relatively low-cost as individuals and the community as a whole can incorporate these building concepts in new buildings as they are built. A combination of some of the above might also be considered (e.g., buildings on plinths can also have an in-house shelter).

It is important to emphasize that the above recommendations provide protection only against moderate storm surges. The only complete guarantee of personal safety for Palmerston Island would be evacuation. Palmerston may want to consider building a small gravel airstrip which could accomodate short take-off and landing airplanes. All Palmerston inhabitants could be evacuated to Rarotonga or another safe island by planes already in the Cooks in just a few trips. This option is becoming more feasible due to improved storm tracking and storm protection procedures. While an airstrip would be costly, it would provide Palmerston with economic development benefits as well as storm protection.