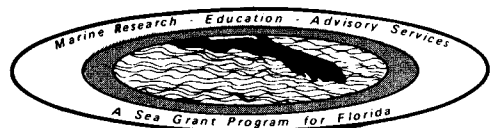


FLORIDA COOPERATIVE EXTENSION SERVICE



# Marine Advisory Program

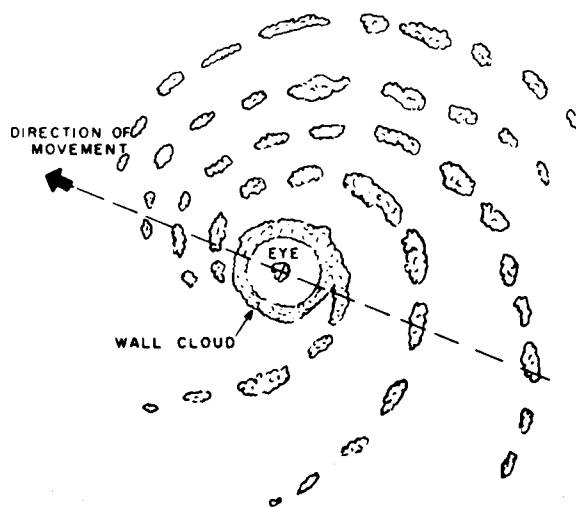
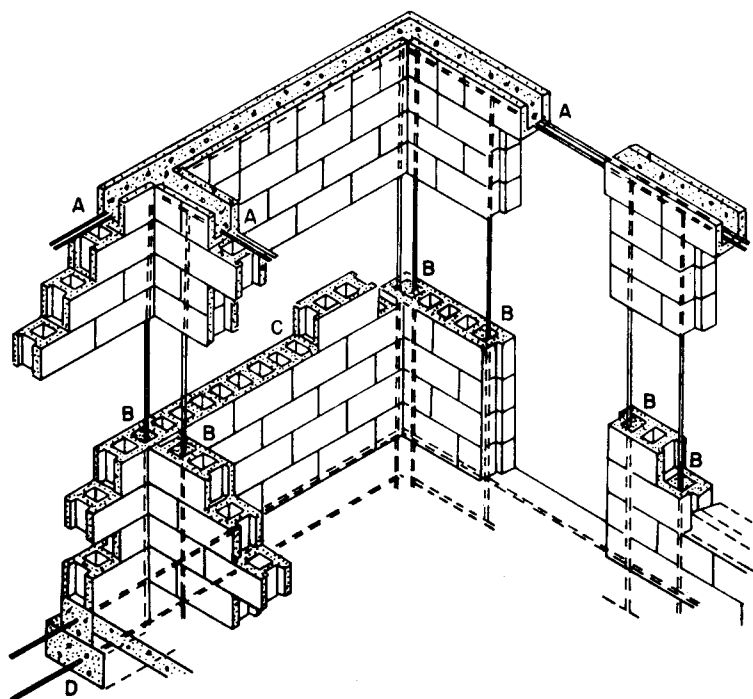
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## Hurricane-Resistant Construction for Homes

by Todd L. Walton, Jr.



**HURRICANE-RESISTANT  
CONSTRUCTION FOR HOMES**

by

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## I. INTRODUCTION

The vast majority of coastal dwellings in Florida have never experienced either high wind or flood water forces. Florida's rapid rate of development has caused an explosion of residential construction in the hazardous coastal strip bordering on the ocean, gulf, and large bays. Unfortunately, most newcomers to Florida's coastline do not realize the hazardous zone they are building in and consequently fail to build their homes accordingly. In some areas local building codes adequately protect the new coastal homebuilder or owner from the forces of nature (wind and water). Additionally, presently proposed regulations concerning the National Flood Insurance Program<sup>(1)</sup> provide guidance to protect against flooding of old and new homes, and regulations to govern any new construction in flood hazard areas. In many areas though, inadequate regulations exist with regard to construction against wind and water hazards. It is for these areas that this publication will be of most use. In areas of existing regulation, a homebuilder may still wish to adopt a more conservative attitude toward construction of his home. Also those who have already built under previously inadequate or nonexistent regulations may wish to make their home more "hurricane proof" by modifications to the existing structure. This pamphlet also provides guidance for these people.

## II. A REVIEW OF HURRICANE WINDS, STORM TIDES, AND DAMAGE ASSESSMENT

"Hurricane" is one of several names given to the tropical cyclones which form over many oceanic regions in the tropics and subtropics.

The term "tropical cyclone" is a descriptive name for a low pressure area originating in the tropics, around which the wind circulation is counterclockwise in the Northern Hemisphere or clockwise in the Southern Hemisphere. The term "hurricane" refers to an organized tropical cyclone having winds of at least 74 statute miles per hour (mph). In the United States and the Caribbean region, weaker tropical cyclones are referred to as tropical storms if the sustained winds are between 39 and 73 mph, and as tropical depressions if the wind speeds are less than 39 mph.

Hurricanes, and tropical cyclones in general, form only over the warm tropical oceans where the water temperature is warmer than about 79°F between 15-35 degrees North or South. They form primarily during the months from June through October when the ocean temperatures are warmest. There are important seasonal changes in the areas of hurricane formation which are due to factors other than ocean temperature; one of which is the relative frequency of weaker

weather disturbances. A large portion of the hurricanes occurring in May and June form in the Gulf of Mexico while a relatively small percentage of the July and August hurricanes form in this region. Similarly, the relative frequency of hurricanes in the western Caribbean is much greater in October and November than in August and September. An inspection of hurricane track charts over a long period of time reveals that most of the August and September hurricanes affecting Florida form east or north of the Antilles and approach from the southeast. In contrast, hurricanes affecting Florida in October and November form primarily in the western Caribbean Sea and reach Florida generally from the southwest. These differences are related to seasonal changes in the large-scale atmospheric circulation patterns, including the Bermuda High and the circulation features at upper levels over the western Atlantic and Caribbean regions.

The hurricane can be viewed as a low pressure area into which the air near the earth's surface is entering along counterclockwise spiral paths. The warm moist tropical air ascends near the storm center and the energy released by this process serves as the primary driving force of the storm. The generation of the high wind speeds within the hurricane and the direction of rotation of the storm can be explained from physical laws in view of the flow of air toward the center and the rotation of the earth. The inflow of air into the hurricane at the lower levels is balanced by an outflow at higher levels and this is often evident from the character of the cirrus clouds which may appear well in advance of the storm center.

The hurricane has several distinctive structural features, the best known of which is probably the so-called "eye" of the storm (see Figure 1). Within the eye there is a marked reduction of wind speed, the heavy rain ceases and there is usually at least a partial clearing of the sky. In the most spectacular cases, the wind speed drops to nearly calm over an appreciable area and nearly all clouds disappear. The eye is usually circular in shape, the size of which can vary from 10 to 100 miles in diameter. All tropical cyclones tend to develop an eye by the time the wind reaches hurricane force.

Surrounding the eye of the hurricane is the so-called wall cloud (see Figure 1). In the best developed cases, this cloud structure completely encircles the eye and extends from earth's surface to above 50,000 feet. This cloud system which is often shown very clearly by radar is typically less than 10 miles in width. The strongest wind speeds are usually found in the wall cloud, only a few miles outside the edge of the eye, and it is in this area that the pressure gradient is strongest and the rainfall is heaviest.

In approaching the center of the hurricane from the outer edge, the pressure falls slowly at first and then rapidly near the storm center (see Figure 1). In tropical cyclones which barely reach hurricane intensity the minimum sea level pressure is seldom lower than 990 mb of mercury, or about 29.2 inches of mercury on a barometer, but in the most intense cases the central pressure often falls below 920 mb, or about 27.2 inches. The lowest pressure ever observed in a hurricane is 892 mb (26.35 inches) which occurred at Matecumbe Key, Florida, during the Labor Day hurricane in 1935.

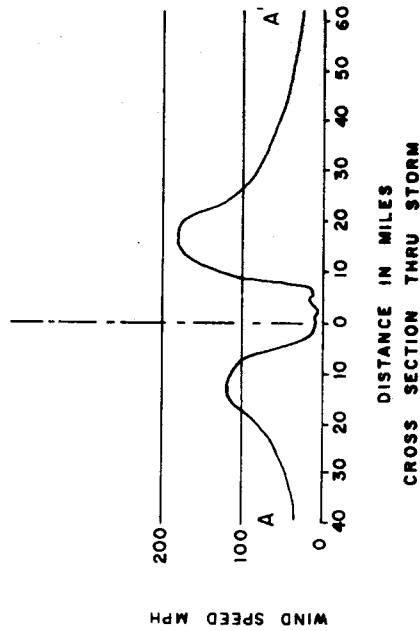
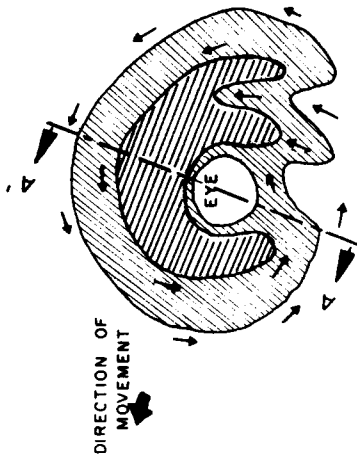


Figure 1a. A plan and elevation view of hurricane rain clouds. Cloud types shown are cumulonimbus (CB), altostratus (AS), stratus (ST), and cirrus (CC). Cirrus clouds cover over the entire storm, and low stratus (scud) clouds hide the upper cloud structure from the ground.

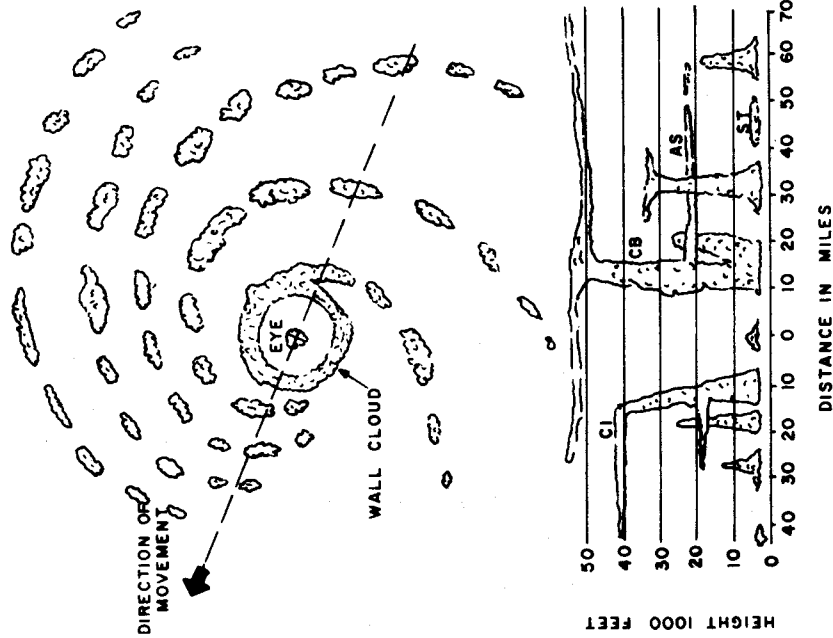


Figure 1b. A representation of the wind distribution around the eye of severe hurricane. The small arrows indicate the wind direction within the hurricane. The light hatching indicates the area of hurricane strength winds. The darker hatching indicates the area of winds greater than 100 miles per hour.

Prior to discussing hurricane winds, a few comments and definitions on wind structure are necessary. As a first step we will consider only winds of constant speed. Winds increase with height, due to the frictional effect of the ground surface, therefore when discussing wind speeds it becomes necessary to reference the height at which wind speed is taken or else reduce a wind speed to a standard height given an appropriate engineering formula. The standard height to which most wind recordings are made or reduced to is 30 feet. The wind velocity profile is influenced heavily by the roughness of the terrain over which the wind is blowing. As the terrain gets rougher (i.e., more buildings, more trees, shrubs, etc., more undulating topography) the velocity profile becomes retarded as in Figure 2. The wind profiles shown in Figure 2 show a typical change in winds from the situation at the coast to a situation a few miles inland from the coast.

The wind considered so far was blowing steadily, but in fact, from anemometer records we know that there is a great deal of turbulence in the atmosphere and the wind does not blow steadily. Curves D and E in Figure 3 are based on data taken at Brookhaven Laboratories during an extratropical storm of November 25, 1950. The wind was blowing over the ocean from the east and occasionally the northeast. The curves are "best fit" estimates to an engineering formula for the wind velocity profile. The station is several miles inland from the coast but is in a coastal area. Curve D is fitted to the maximum 6 minute velocity averages while curve E is fitted to the "peak" gusts experienced in the storm. As can be seen in this storm the "peak" velocities are on the order of 50% higher than the 6 minute average wind velocities. The longer the averaging time of the velocity, the lower peak velocity becomes. Hence, it is necessary to define a measure of the wind speed averaging time. The "fastest mile of wind" is a measurement of the average velocity traveled by the wind in a distance of one mile. As an example, if the wind was blowing at 120 mph (or 2 miles per minute) then the time it would take the wind to travel 1 mile would be 30 seconds, hence a "fastest mile of wind" of 120 mph would represent a 30 second time average of the wind. This wind speed averaging time is important in the design of structures.

Wind speeds mentioned in this publication, unless otherwise stated, are "fastest mile of wind" speeds.

The maximum wind speeds in hurricanes are closely correlated with the sea level pressure at the storm center. In hurricanes with central pressures below 920 mb, wind speeds near the earth's surface may exceed 150 mph with gusts some 25-50 mph higher. There are relatively few measurements of sustained wind speeds above 130 mph since most wind equipment is blown down or becomes inoperative at extreme speeds.

The highest wind speeds which have been reliably measured in Florida are probably those observed at the Hillsboro lighthouse during the hurricane of September 1947. The maximum wind speed averaged over one minute was about 155 mph and the highest five minute average was about 121 mph. During the hurricane of August 1949 the wind equipment at the Jupiter lighthouse failed after recording a value of nearly 153 mph and it was felt that higher speeds probably occurred after the time of the equipment failure.(3)



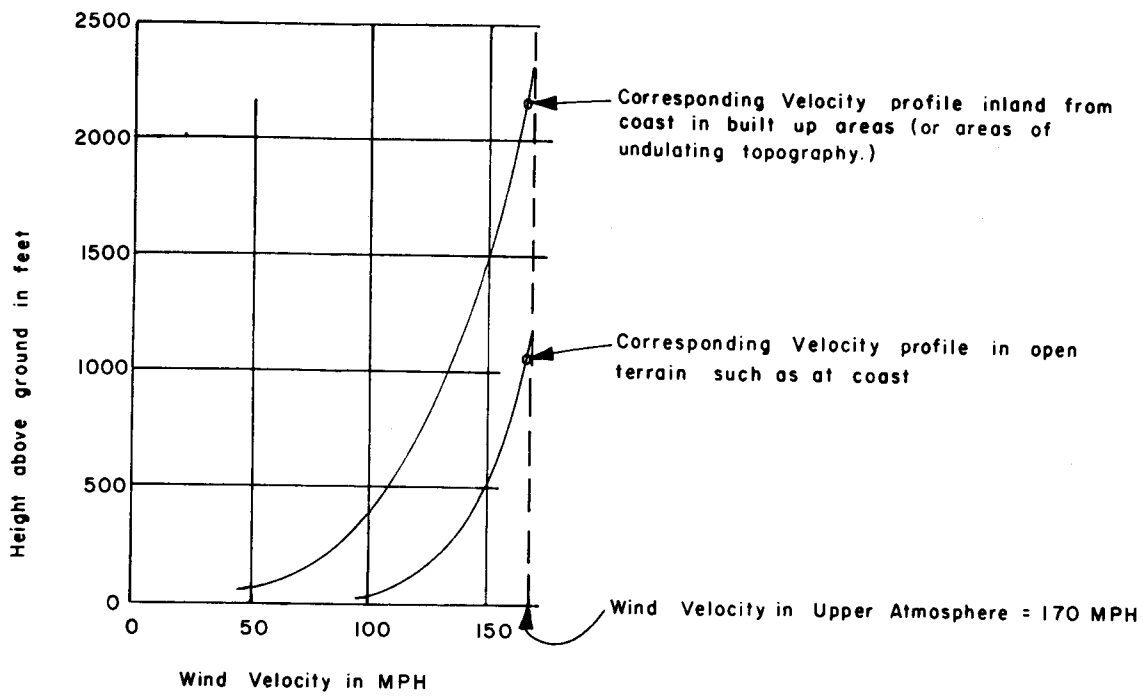


Figure 2. Influence of Terrain on Wind Velocity Profile.

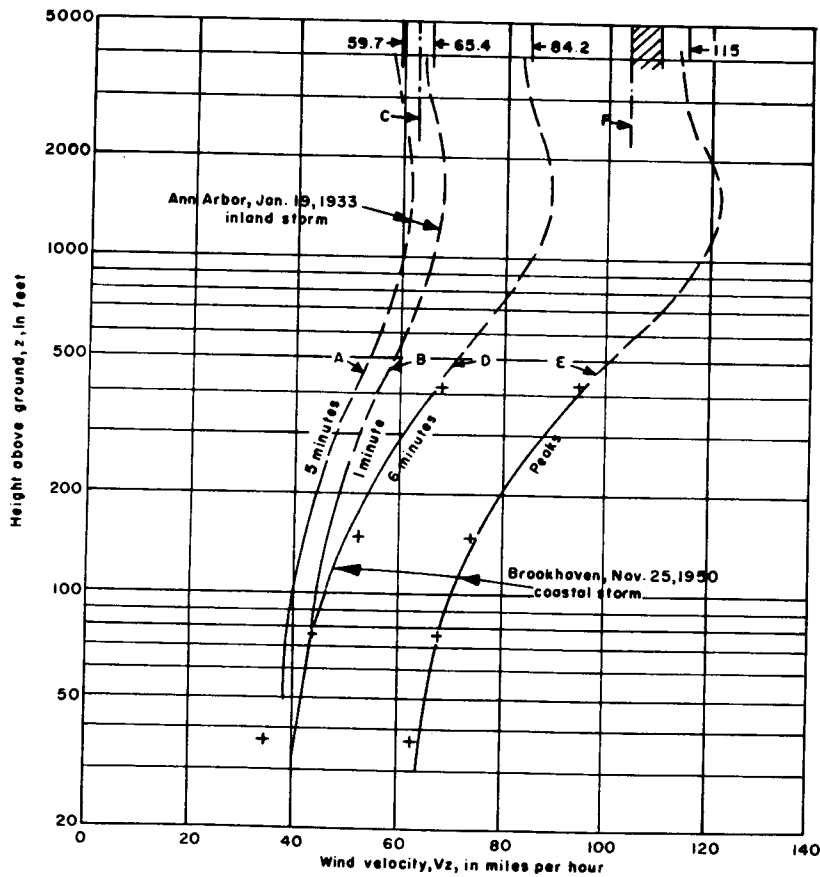


Figure 3. Wind Velocity For Extratropical Storms From Reference (2).

In Hurricane "Camille" which struck the Mississippi coastline in August, 1969, a reliable wind speed estimate of 172 mph (fastest mile of wind) was recorded 100 feet above the water on an offshore drilling platform. When reduced to a height of 30 feet above the ground this would give 115 mph (fastest mile of wind) or 144 mph for the peak gust.(4) This study found a storm of Camille's intensity to have a recurrence interval of 160 years in that area of the Gulf.

In August, 1970, Hurricane "Celia" struck the Texas coast with recorded winds of over 161 mph. Estimated peak gusts from this hurricane were on the order of 180 mph.(5)

Estimates of maximum wind speeds for some of the major storms of hurricane force hitting Florida since 1900 are given in Table 1. It is apparent that high wind speeds are relatively common along our coast and that no area is invulnerable to exceptional wind speeds. A discussion of the probability of such wind speeds hitting any given area will follow in a later section of this publication.

A hurricane usually weakens very rapidly after moving inland (as shown by many studies of individual hurricanes). This weakening is due primarily to the removal of the energy source provided by the warm tropical oceans and the friction exerted by land surface. Along with this storm weakening, winds are also reduced to the extent that a few miles inland from the coast wind speeds may be only 60-70% of their speed at the open coast.

Unfortunately, winds are not the only damaging forces brought by hurricanes. Over 70% of all damage in hurricanes is done by flooding. Maximum values of tide heights that have been observed during major hurricanes along Florida's coast are indicated in Figure 4. The numbers in circles refer to the hurricanes indicated in Table 1. It should be noted that many of these tidal heights are only approximations from water level marks on buildings and not levels from tide gage records.

An additional record of tidal heights experienced in Hurricane "Donna" 1960 is shown in Figure 5. The path of the storm is shown by the hatched strip on the figure.

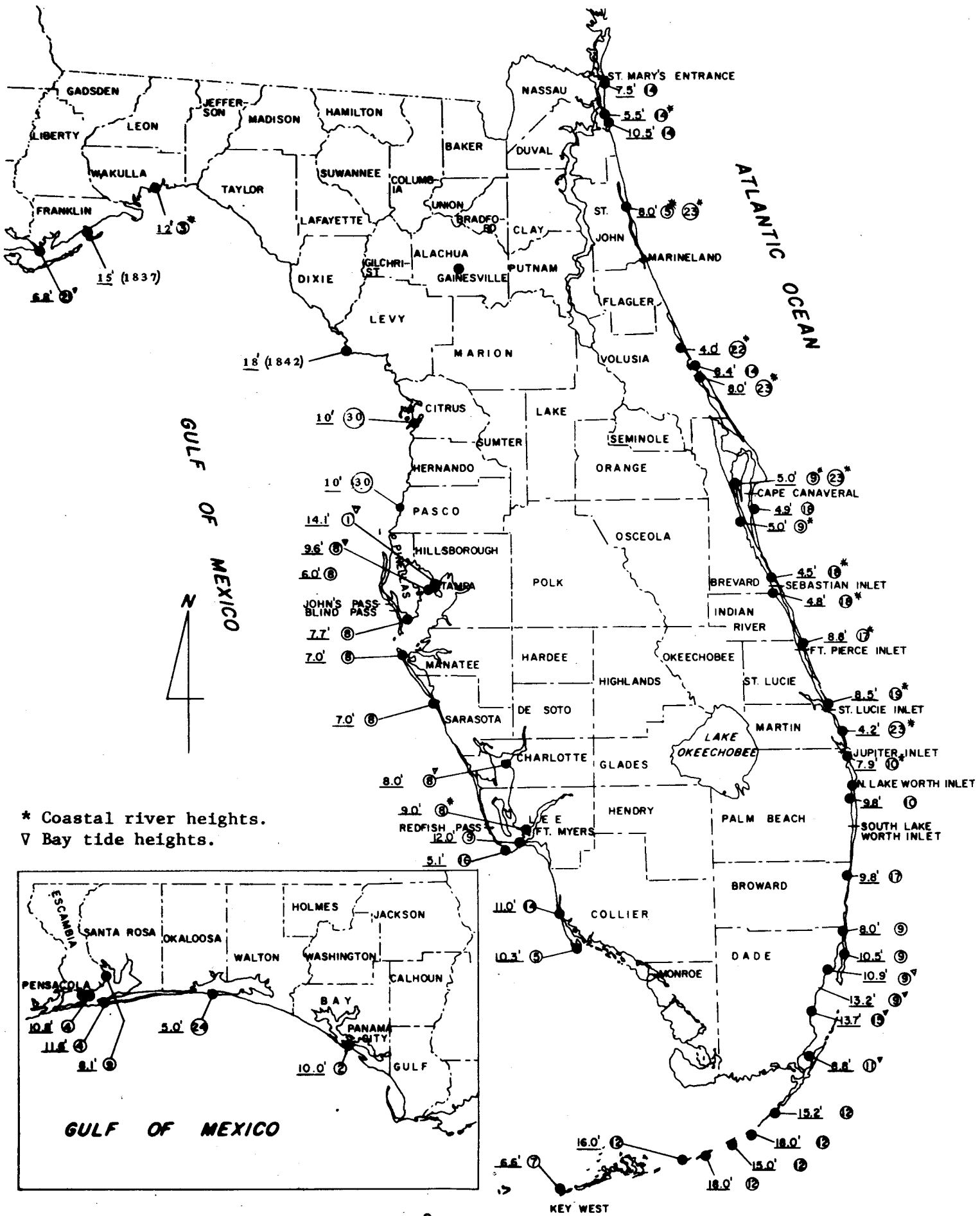
The height of a storm surge depends on a number of meteorological factors of the hurricane and on the offshore bathymetry of the coastal area in question. Wide continental shelves with shallow depths of water have higher storm surges than narrow shelves with deep depths offshore. The storm surge in a given area is also proportional to the pressure drop at the hurricane center. The greater the pressure drop, the more severe the storm surge. Other factors which influence the storm surge are the radius to the maximum winds and the velocity of the storm system. Storm surge is highest in the right front quadrant of a hurricane where the onshore winds are strongest.

TABLE I

STORMS OF HURRICANE, OR NEAR HURRICANE  
FORCE STRIKING FLORIDA SINCE 1900

#	Date	Maximum Estimated Wind Speed mph	Lowest Barometer Inches Mercury	Point of Impact & Course
	9/31/1837	?		?
	10/1842	?		?
1	9/1848	?		Tampa Area
2	8/1856	?		Panama City
3	8/1851	?		St. Marks
4	9/27/1906	83-100	28.84	Mobile, Alabama
5	10/17/1910	100	28.40	Lower Keys, Sand Key - Sarasota
6	9/04/1915	70	29.62	Apalachicola
7	9/14/1919	120	28.81	Key West (27.51 @ Dry Tortugas)
8	10/25/1921	80-100	28.29	Tarpon Springs - Titusville
9	9/18/1926	138/152	27.61	Miami, Bonita Springs- Reentry at Pensacola (wind 152MPH at Pensacola)
10	9/16/1928	125	27.43	Palm Beach-Canal Point - Ocala & North
11	9/28/1929	150	28.00	Key Largo-Reentry Panama City - 28.80
12	9/02/1935	200	26.35	Long Key-Islamorada-(reenter at Cross City)
13	11/04/1935	94	28.73	Miami (Reentered at Tampa)
14	10/18/1944	120+	28.02	Dry Tortugas-Sarasota
15	9/15/1945	170	28.09	Homestead -
16	10/07/1946	80	29.16	Fort Myers to Ceder Key and Jacksonville
17	9/17/1947	155	27.97	Ft. Lauderdale-Pompano-Naples at 105 MPH
18	9/21/1948	122	28.45	Key West to Hillsboro Light
19	10/05/1948	100+	28.80	Sombrero Light - Westward
20	8/26/1949	153	28.17	Jupiter Inlet & West Palm Beach, Lake Oke- eehobee at 100 MPH
21	8/30/1950	72	28.92	Mobile, Alabama
22	9/04/1950	125	28.30	Cedar Key - (Rainfall 24 inches)
23	10/17/1950	122	28.20	Miami (violent but small)
24	9/24/1956	120	28.93	Valparaiso and Pensacola
25	9/10/1960	120	27.55	Conch Key, Tavenier, Naples, Ft. Myers, Day- tona - See "Donna"
26	8/27/1964	125	28.57	Miami - "Cleo"
27	9/09/1964	100	28.52	St. Augustine and Jacksonville "Dora"
28	10/14/1964	90	28.67	Dry Tortugas - Everglades City
29	9/08/1965	140	28.12	Upper Keys - "Betsey"
30	6/10/1966	110	28.65	West Coast of Florida

Figure 4. Historical Maximum Storm Tide Levels in Florida.



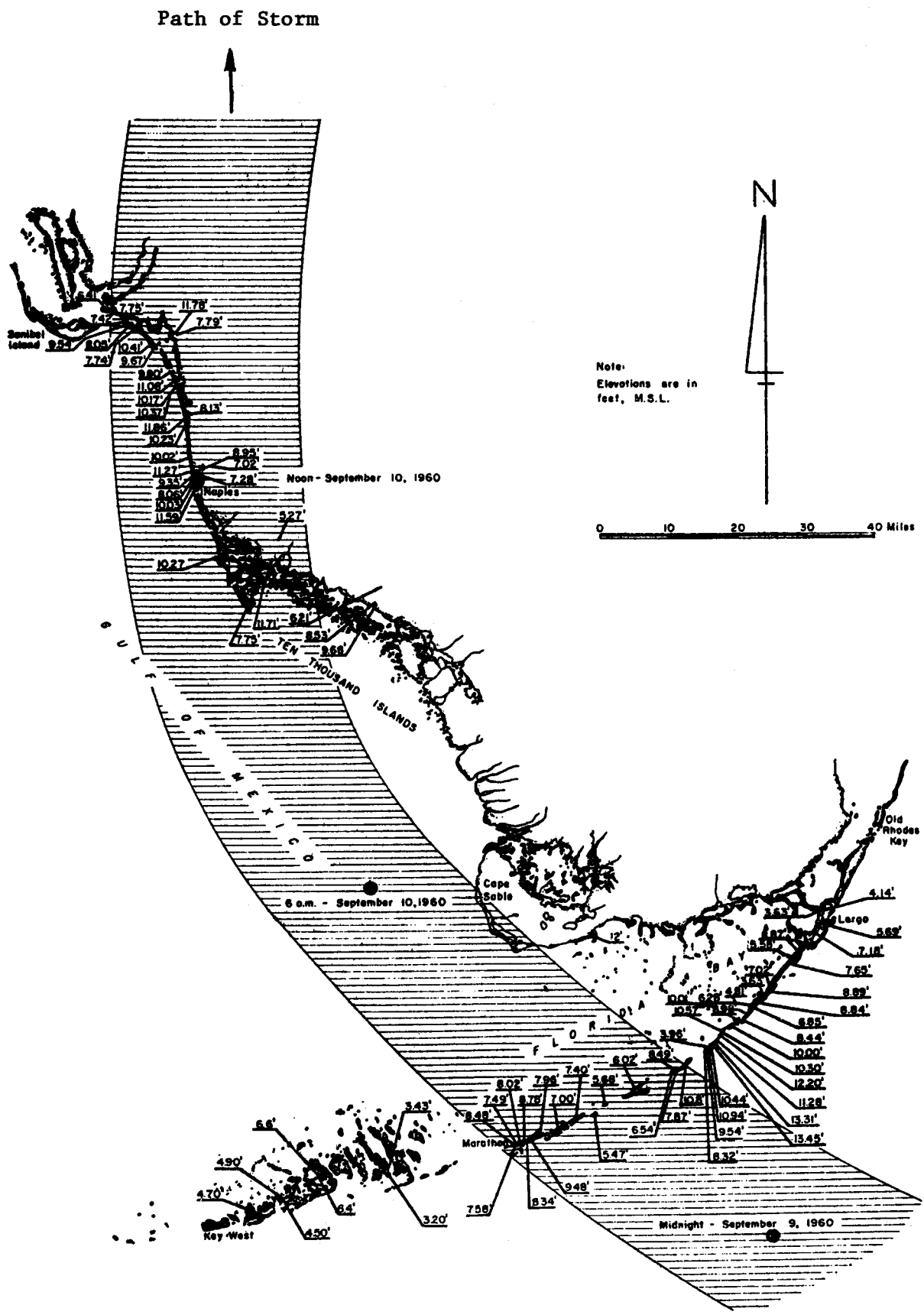


Figure 5. Hurricane Storm Tide Levels due to Hurricane "Donna". From Reference (3).

As an example of the length of coast over which a storm surge can have an effect, Figure 6 from Reference (4) is presented showing both estimated sustained wind speeds and actual tide levels (above mean sea level) along the Mississippi-Alabama coastline for Hurricane Camille.

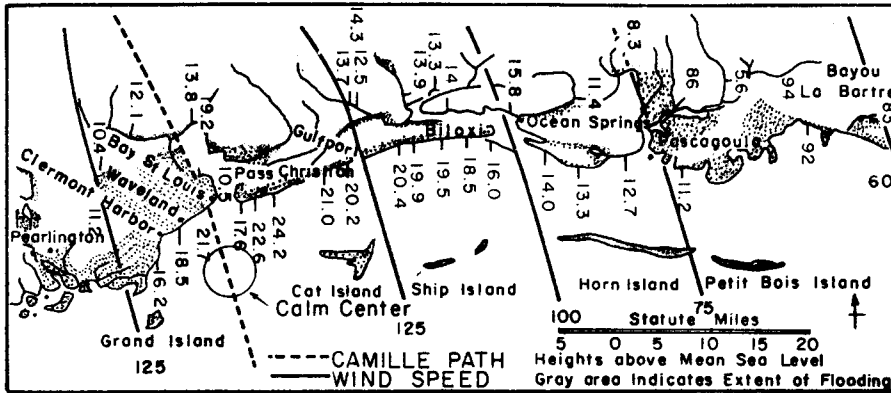


Figure 6. Onshore wind speeds, surge heights, and extent of flooding due to Camille, from reference (4).

### III. A QUICK REVIEW OF SOME PROBABILITY CONCEPTS AND THEIR IMPLICATIONS ON HOME DESIGN IN HAZARDOUS AREAS

Disastrous events of a nature such as hurricanes, tornadoes, and earthquakes are impossible to predict due to their probabilistic nature. The occurrences of such events are random and each event is independent of both the prior history of the area in question and past recorded events of a similar nature. The fact that an extremely destructive event has never hit a given area in historically recorded time does not preclude such an event from occurring in the future. In effect, this means that a storm such as Hurricane "Camille" which hit the Gulf coast in 1969 (the most severe hurricane in recorded U.S. history) could hit anywhere along the Florida East or Gulf coast in any given year. The probability of such a storm hitting varies, depending on the area of interest.

Due to the probabilistic nature of meteorological events such as extreme wind speeds and consequent extreme (wind tide) water levels, meteorologists and scientists categorize events by their probability of occurring in any year based on historical trends of similar data.

An event (a storm tide or extreme wind speed) which has a one percent chance of occurring in any given year is referred to as the 100 year event (i.e., 100 year storm tide or one hundred year wind speed).

What this means, in other words, is that an event of this magnitude (say for example a 12 foot storm tide) might be expected on the average once every one hundred years.

This event is defined as having an average return interval of 100 years (where return interval =  $1/\text{probability of occurrence in one year} = 1/0.01 = 100$  years).

Contrary to what many people believe, this does not mean that once a one hundred year storm tide occurs (in our example a 12 foot storm tide) that it will be another 100 years before a similar storm with a 12 foot or greater tide level reoccurs. In fact another 12 foot storm tide could occur the next year or even in the same year. In both Florida and Texas two "estimated" 100 year storm tides have occurred within a span of 10 years. (3,5)

Our present inability to predict such disastrous events with certainty makes it important to realize the degree of our conservativeness when building in a hazardous zone such as the coastal zone.

We can tell how conservative we are in our design by means of probability theory and what mathematicians refer to as the "binomial theorem". The results of this theorem and of probability theory are summarized in Figure 7. On the lower portion of this graph is the encounter period ( $=N$ ) or the period for which a structure might be designated to last. In the case of home design, the encounter period might be 50 years which would represent the period in which a family might depreciate its home for tax purposes or might reasonably expect their home to last. Curves on this graph are for different return periods ( $=Tr$ ). The encounter probability ( $=Pn$ ) on the left of the graph represents the probability that an event with a designated return period will be equaled or exceeded during the encounter period selected.

As an example of how to use this graph, consider that you would like to build your home on the coast and would like the house to be relatively safe from a 12 foot storm tide occurrence which happens to be the one hundred year storm tide in your area (information as to storm tide levels in Florida will be discussed later in this publication). The probability of the 100 year storm tide being equaled or exceeded during a 50 year period is 0.4 (from the graph the encounter probability  $Pn=0.4$ ). That is, there is a 40% chance that a storm tide of 12 feet or higher will occur in the desired design life-time of that house.

Had you designed your house for a 500 year storm tide or wind speed ( $Tr = 500$ ), probabilistically speaking your house would have a much better chance of surviving the critical event. The probability of the 500 year storm tide being exceeded in the 50 year life of the house would be only 0.1 or 10 percent, a much more acceptable risk level.

Using this graph in another manner, if you are willing to take a 20% chance of a storm tide (or wind speed) exceedance during the design life of your house ( $Pn = 0.2$ ) and want a design life of 50 years, then the return period of the storm which you should design for is  $Tr = 250$  years. Thus assuming a 20% risk level both a 250 year wind speed and a 250 year storm tide should be considered for design. It is worth noting that Hurricane Camille with its tremendously destructive force had an estimated return period of only 160 years. (4)

It should be mentioned at this point that practically all regulations (both federal and local) governing building in hazardous zones specify minimum design criteria using the 100 year event (storm tides and wind speeds). One who is building in a hazardous zone should be aware that

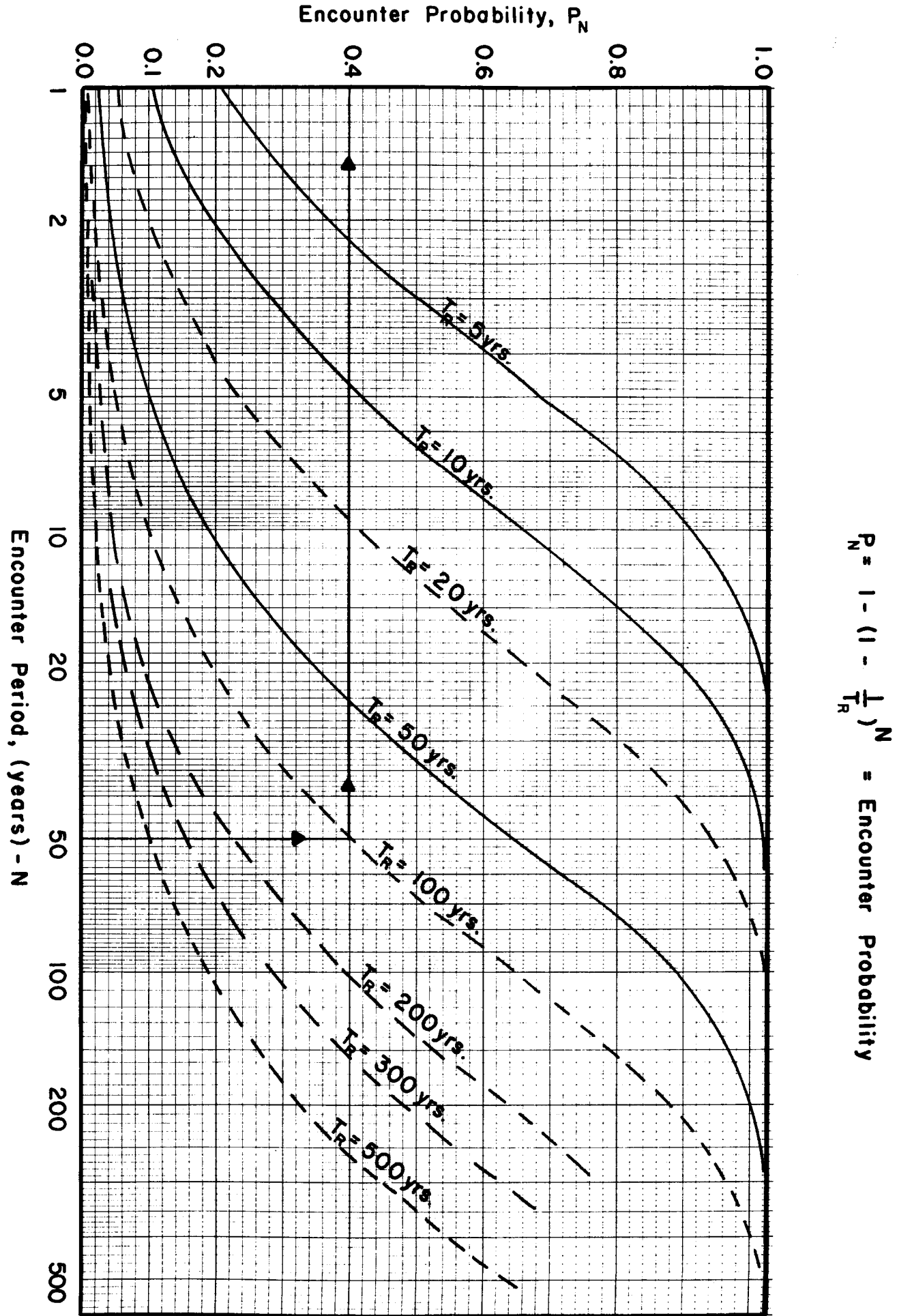


Figure 7. Encounter Probability Versus Encounter Period.



protective measures built into laws and zoning ordinances may not be as conservative as he (or she) thinks they are. Realizing this, one might wish to be more conservative than is minimally necessary to comply with the law, and specify that his (or her) structure be designed for a 500 year event or greater. This is a decision that should be made by a home buyer and relayed to the engineer or architect who can in turn design the house to the level of risk which the buyer is willing to accept.

#### IV. REVIEW OF PERTINENT FEDERAL AND LOCAL GUIDELINES

Existing federal programs and state and county building ordinances protect many people living in the coastal zone to some degree. The existing National Flood Insurance Program (1) presently regulates those buildings in the coastal zone in designated "flood hazard" areas ensuring that such buildings shall maintain some degree of protection against flood waters.

The Flood Insurance Program is similar in nature to other zoning concepts only it is on a national level. Essentially the program requires local communities to adopt Flood plain zoning as a requirement to obtaining federal mortgage loan funds. One typical requirement of the program is that the first habitable floor level of all new buildings is to be above the 100 year flood level (or storm surge level on the coast) to qualify for federally subsidized flood insurance. All construction in flood prone zones will be required to have flood insurance to obtain a mortgage loan from any Federally subsidized or insured savings and loan institution. Conformance with the specified requirements of the National Flood Insurance Program will qualify a home-builder for "federally subsidized" insurance whereas those not in compliance will have to purchase more expensive unsubsidized insurance to obtain a house loan. Local communities may also have additional restrictive flood zoning measures depending on the area.

Various counties and other local governmental regulating bodies have building codes that give a level of protection by assurance that the 100 year wind loadings are considered in design. One such code that has had input from engineering groups studying the effects of damage due to high winds in hurricanes is the South Florida Building Code. This code is considered by many to be the best existing code for protection against high wind damage. In most building codes though no protective measures to prevent water damage are provided for.

In most areas where regulations exist, they cover only protection from wind forces and therefore are not comprehensive in their coverage to guarantee the best construction practices for optimum protection against hurricanes. The homebuilder or buyer should therefore understand the type of protection provided in his local building codes.

The following section describes some of the most pertinent information which the homebuilder or buyer should be aware of in these regulations and ordinances.

## National Flood Insurance Program

The National Flood Insurance Program is a program established by Congress to provide flood insurance at federally subsidized rates. To qualify for this program a community must adopt and administer local measures to protect new construction from future flooding. Specific measures must be adopted within a community that will prevent damage to structures in designated "flood hazard" zones by any flood (or storm tide) less than the 100 year event. At the time of this writing many communities were under this program. Most county building and zoning departments now have maps delineating flood hazard areas along with the 100 year storm tide elevation. One of the specific protective measures that applies to most areas in the adopted regulations provides that all new construction will have the first habitable floor elevation above the level designated as the 100 year flood level. Below this level only "breakaway" construction (designed to fail in moving water but not tied in to the main structural framing of the building such that failure of breakaway wall(s) will not endanger the structure) will be allowed. Two points of importance come up here. As noted in the discussion on storm tides, the overall water level in a hurricane storm tide is made up of a number of factors; wind, tide, barometric setup, astronomical tide (normal tide caused by sun and moon) and water wave effects such as wave runup and wave setup. In the calculations made for the 100 year storm surge no water wave effects have been considered. Thus if a 100 year storm tide were to occur these additional wave effects could still pose a damaging effect on the building. This limitation to the regulation is taken into account by the designating of a "coastal high hazard" area. This designation on a Flood Insurance Rate Map designates your area as having potential damage from wave action assuming the 100 year storm tide occurs, and consequently has a higher insurance rate. The "coastal high hazard" area, practically speaking, is defined as the area in which a 3 foot wave or larger can be supported on top of the 100 year storm surge. A three foot wave is judged to be the limiting wave which would cause damage to a typical residential type structure<sup>(7)</sup>.

From the standpoint of safety a homebuilder would be wise to build the first floor elevation above the 100 year flood elevation if his house is in an exposed coastal or bay area where wave activity can pose an added threat. The problem of defining the 100 year flood level for combined storm surge and wind wave effects is a highly technical endeavor depending on both meteorological parameters and the hydrography and topography of the area and has not yet been done.

A reasonably conservative approach to use for determination of first floor elevation of a house in an exposed coastal location is to build the first floor elevation a distance  $h_w$  higher than the designated 100 year flood level, where  $h_w = 0.8 \times (100 \text{ year flood level} - \text{ground elevation level})$ . This approach of determining peak surge level is based on a very simplistic model for calculating the maximum superimposed wave height on a still water 100 year flood level.

As an example, consider a barrier island on the Gulf coast of Florida with an elevation of +6 feet MSL (mean sea level). Assume the 100 year storm tide was obtained from the county building and zoning department as +12 feet mean sea level. Then a conservative ocean side elevation of a home would be 12 feet + 0.8 (12-6) feet = 16.8 feet MSL, 100 year tide + 0.8 X (100 year tide - grade evaluation). This would put the first floor elevation of the house 10.8 feet

above grade level (i.e., 16.8 feet MSL - 6.0 feet MSL).

Additional regulations governing the use of breakaway walls in areas below the 100 year storm surge level do not define what a breakaway wall would be. This author would suggest that if breakaway walls need to be used, the breakaway wall should be one which could survive reasonable high wind forces (170 mph) and yet not be tied rigidly into the existing structural frame of the building. The wall would fail under extremely high wind forces (> 170 mph) or under wave and water forces not endangering the structural integrity or habitable portion of the building. Additionally, the wall should be heavy enough not to be carried with the wind or floated away by water causing damage to other structures. In this regard, it is important to note that law suits have risen in Texas over structures damaged by wind carried signs and awnings which blew off neighboring structures during strong winds (8). Similar suits may arise due to damage caused by floating objects in hurricanes.

A professional engineer or architect should be consulted for suitable design of a breakaway wall until guidelines are developed.

#### State of Florida - Coastal Construction Setback Line

Along the open coast portions of Florida, in areas where there are sandy beaches, an existing state regulated coastal construction setback line is in effect (9). The established setback line represents a line beyond which any building construction will require a variance from the Bureau of Beaches and Shores, Department of Natural Resources, State of Florida. The setback line program is well detailed in reference (9). The objectives of the setback line are: "to prevent beach encroachment that would endanger the existing beach-dune system and to help prevent existing and future structures from being unreasonably subject to great and irreparable harm." As pointed out in reference (9), "compliance with no construction seaward of the recommended setback line does not imply that structures can be built without giving detailed consideration to the problem associated with ocean front development."

Procedures are now under study by the Bureau of Beaches and Shores, as of this writing, to establish what constitutes good building practice within this zone for establishment of a variance.

As the setback line presently does not encompass either bay shorelines, coastal tidal wetlands, or back beach areas, relatively little of the coastal hazard area will be covered by this type of restrictive zoning.

#### County Building Codes

One of three building codes have been adopted by most of the counties in Florida although some counties are still not restricted in their building practices by any type of building code. The three building codes are:

(1) The South Florida Building Code; (2) The Southern Standard Building Code; and (3) the National Building Code.

Each code has its own peculiar restrictions and protective measures. All three codes have a wind loading section for design of buildings which provide for a minimum wind loadings based on the formula  $P = .00256 V^2 \left(\frac{H}{30}\right)^{2.7}$  where

P = pressure in pounds per square foot,

V = velocity of sustained wind in miles per hour,

H = height above grade of area on which P is acting.

The maximum wind speed used in the above formula is 120 mph in the South Florida Building Code (10), and is determined from a chart showing the 100 year recurrence interval wind speed (which depends on location) in the Southern Standard Building Code (11). For comparison purposes it should be noted that certain coastal areas of Texas designate design loads based on winds of 150 mph (12). All codes consider additional modifiers to the basic pressure formula above depending on: (1) building shape; (2) angle of inclined surface (for roof); (3) percentage of open area in surface; (4) vertical surface shapes; and (5) windward or leeward vertical wall factors. Additionally, special surface shape factors apply for overhangs, eaves, screened enclosures, and other special building parts.

Recently, a much more thorough wind loading code was developed by the American National Standards Institute (ANSI) (13). The ANSI wind code is based on the latest technical developments in wind engineering and provides a more realistic approach to evaluating wind loadings on the various parts of buildings. The ANSI code, like the Southern Standard Code, specifies the basic wind speed by means of a recurrence interval wind speed for a given location, a probabilistic concept allowing the designer to pick the level of probability he is willing to accept in his design (see Section III). The basic wind speed in the ANSI code though is modified by both a "gust loading" factor taking into account the turbulent nature of the winds, and an "exposure factor" which depends on the surrounding terrain and setting of the building (i.e., wooded area, center of large city, or exposed location). Additionally the wind speed is modified by a height factor and various shape factors as is done in the other codes, only ANSI is more inclusive in its various shape factors.

A very general comparison of the formulas can be made by comparing the basic wind speeds of the various codes considering the gusting, exposure, and height factors in the ANSI code, and the height factor in the other codes.

For a residential structure located in an exposed location in the Florida Keys extending from 15 - 25 feet above grade, and considering the 100 year recurrence interval wind speed, the following basic wind speeds (which would be modified by various shape factors for design) are obtained:

<u>Code</u>	<u>Basic Wind Speed</u>
ANSI	45#/ft <sup>2</sup>
South Florida	33
Southern Standard	34

In view of the recent research in wind engineering incorporated into the ANSI code and the provision for considering both degree of structure exposure and gust factor, it is recommended that a homebuilder have his house designed by a professional engineer or architect to resist both the local building code suggested wind loadings or the ANSI wind loadings using the more conservative design loadings of the two. In the above example, the ANSI code was seen to be more conservative prior to any shape factor modifications.

Building codes additionally specify types of building anchorage, minimum foundation requirements, maximum glass or glazing requirements, and numerous other important considerations in building. These restrictions are discussed in detail in the specific codes. It should be pointed out here that the South Florida Building Code is considered by many experts to be the best building code in existence for hurricane prone zones due to its continual updating and changing of provisions based on hurricane damage surveys(3).

#### V. SUGGESTED GUIDELINES FOR "HURRICANE-PROOF" CONSTRUCTION

From the observations of various engineering specialists, it appears that any type of construction (i.e. wood, brick, or masonry) can be designed to withstand hurricane force winds if designed properly and in accordance with good engineering practices (3,14). This section is aimed at providing some specific guidelines and information as to where additional guidelines can be obtained for good high hazard area residential construction.

Much of the information within this section can be obtained in two excellent publications: "Houses Can Resist Hurricanes" FPL 33 by the Forest Products Laboratory (15), and "How to Build Storm Resistant Structures" by the Southern Pine Association (16). References (15) and (16) can be obtained by writing to the respective issuing agencies.

#### Wood Frame Construction

Wood is an excellent building material for use in the hazardous coastal zone provided it is properly treated. Specific construction practices which can make the difference in a normal wood frame house and a hurricane proof house are the uses of good anchorage and fasteners. To be structurally sound, a building should be rigidly fastened and have its components properly held together. Proper fastenings throughout the entire building are the key to good construction here. This process begins at the foundation where the wood sill is anchored to the concrete or concrete block foundation wall (see Figure 8). From there fastening should continue from the sill to the wall studs (see Figure 9). Commercial framing anchors and fastenings are available for this type construction which consist of punched metal straps. These type of connectors or variations thereof are used in both the South Florida Building Code and the Southern Standard Building Code and are available at building suppliers in counties utilizing those codes.

At the top of the walls, other type metal connectors can be used (Figures 10,11) to provide a rigid connection between the wall studs, plate, and the roof trusses.

Poor nailing practices are a cause of numerous building failures due to high winds. Reference (15) provides a table of recommended nailing practices to be used for sound construction. This table (Table 2, page 18, Reference 15) should be included into your building plans for the contractor to comply with.

Due to the severe racking forces encountered in high winds it is recommended that wood frame homes use either plywood sheathing or wood sheathing on all

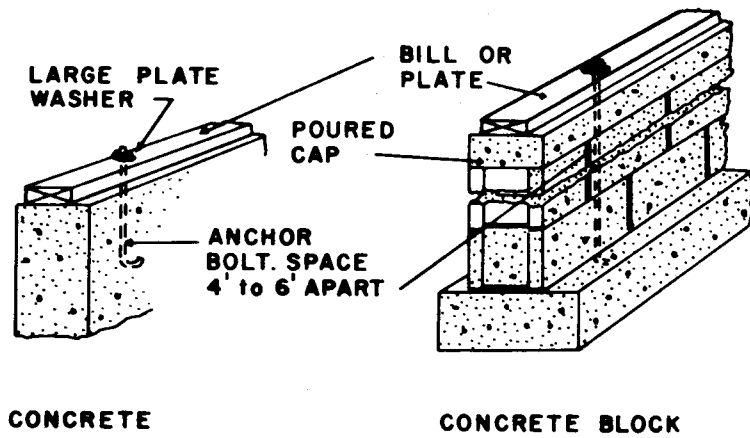


Figure 8. Anchoring wood sill or plate to foundation. From Reference (15).

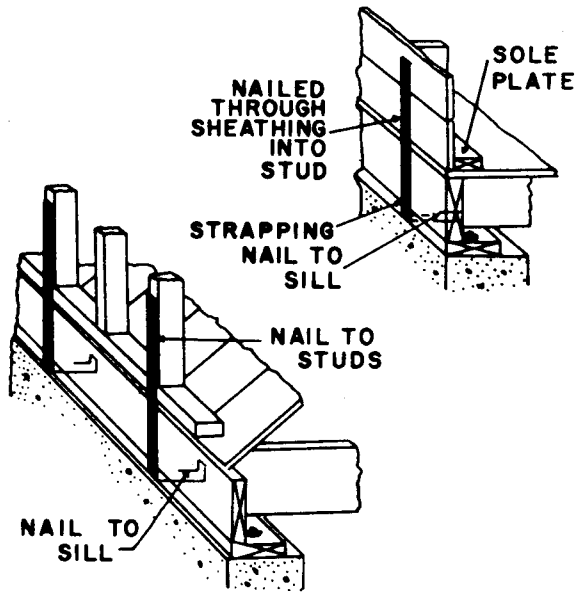


Figure 9. Foundation-to-wall connections: A, straps nailed directly to studs; B, straps nailed through sheathing into studs. From reference (15).

walls of the house to provide good lateral resistance. Additionally, plywood sub-flooring and attic flooring should be used to provide good torsional resistance in the horizontal plane of the house. Reference (15) covers both types of sheathing and shows recommended nailing and connection practices for sheathing. Figure 12 shows a timber frame house which failed in the winds of Cyclone "Tracy" in Darwin, Australia in December of 1974. This house would not have collapsed had the walls been sheathed to provide lateral rigidity. Plywood sheathing also provides good insulation for the energy conscious home owner. Numerous other good timber construction practices are provided in Reference (15). Rather than repeat this information it is best for the homeowner desiring a timber frame home to request a copy of this reference from the source listed.

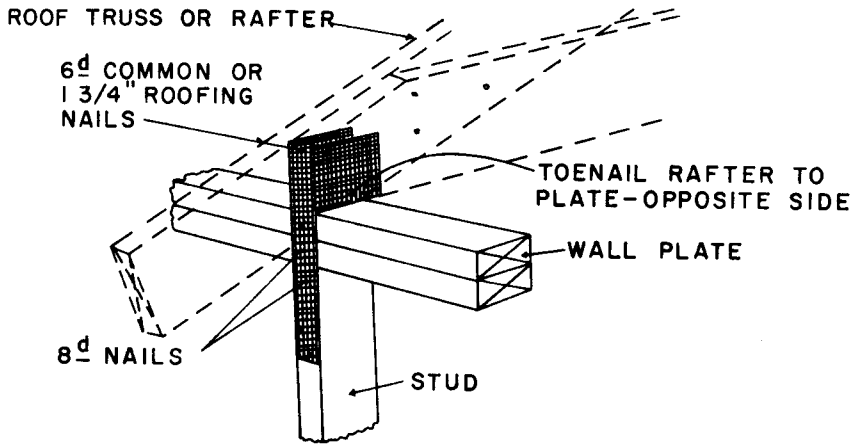


Figure 10. Single member plate connectors. From Reference (15).

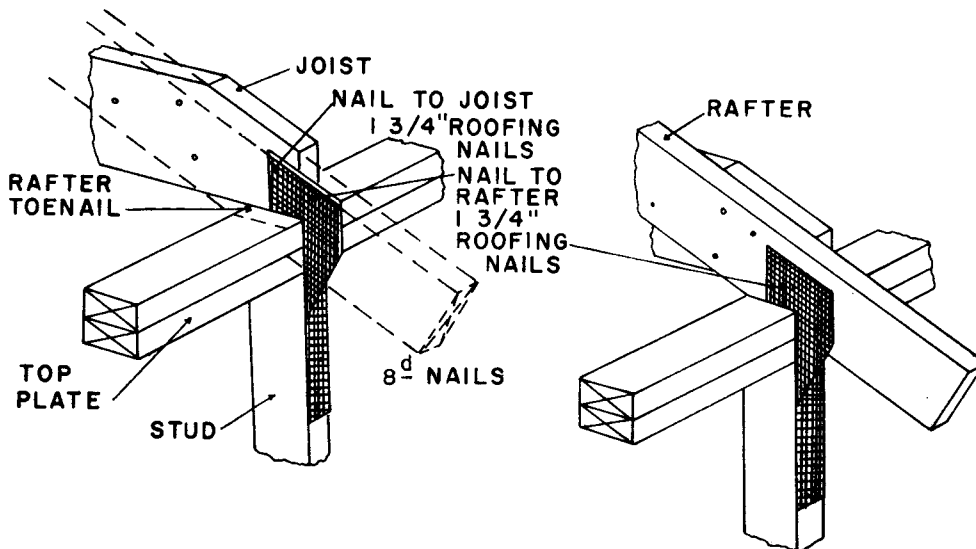


Figure 11. Rafter-to-stud plate connector for: A, ceiling joist over stud, and B, rafter over stud. From reference (15).

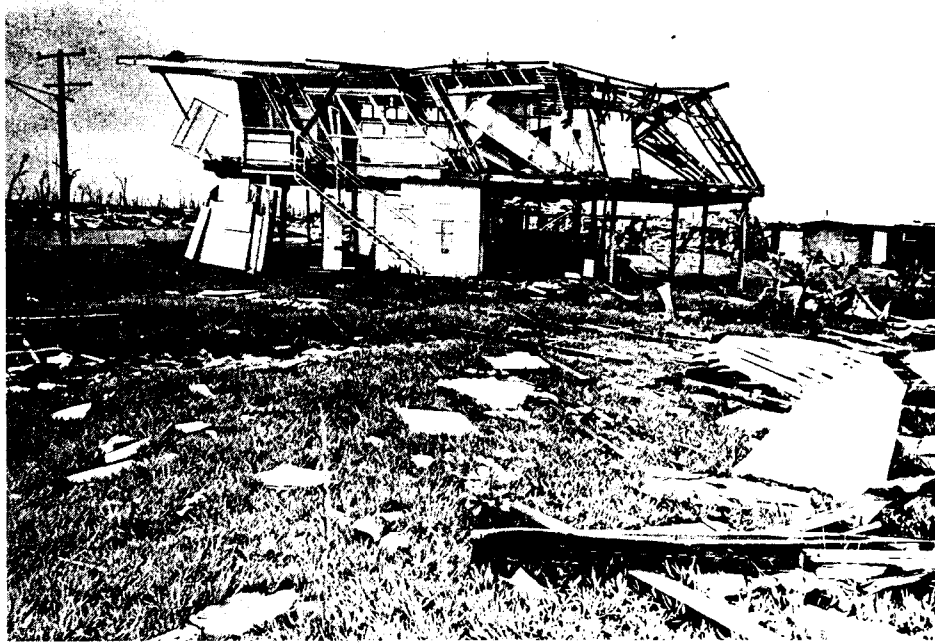


Figure 12. House destroyed by racking force in Cyclone Tracy.

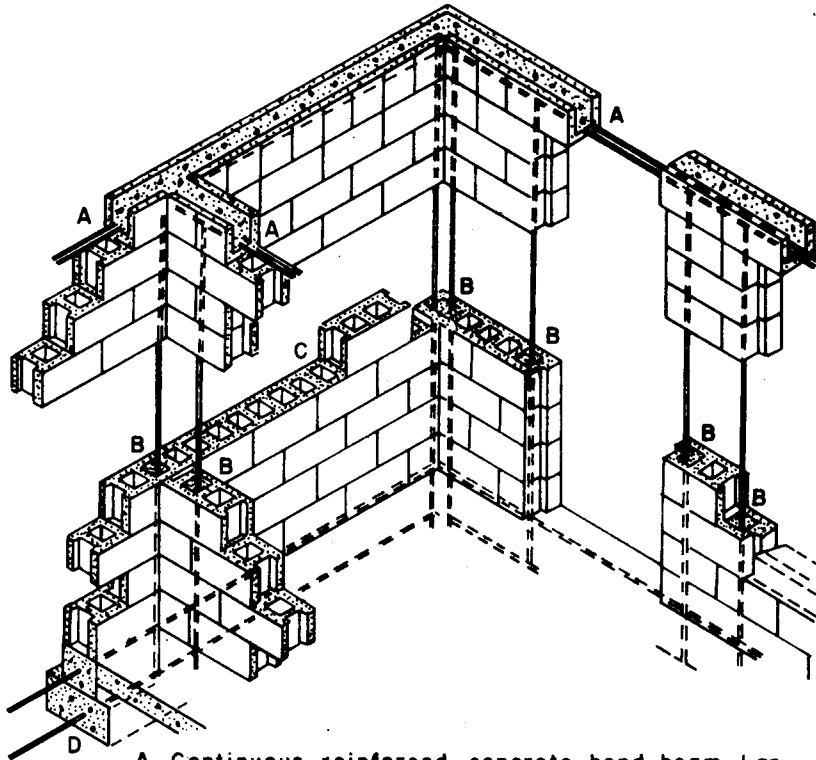
### Masonry and Brick Construction

Unsupported masonry walls of typical residential type construction with a height of 8-9 feet per floor, are adequate to withstand typical hurricane wind forces provided they are constructed in accordance with regulations of either the South Florida Building Code or the Southern Standard Building Code. This would include reinforcement bars internally through the blocks from foundation to ceiling in interior and exterior corners of the house and at all framed doors or large windows for the case of masonry block walls (see Figure 13). A continuous reinforced concrete bond beam completes the top layer and should be adequately tied into the roofing system by metal fastenings (hurricane clips) or some method of bolting.

The exterior surface of concrete block walls should be stuccoed or water proofed in some manner to resist rain penetration (3,21). The interior of concrete block walls should have furrings strips and then interior cladding to reduce any through the wall moisture penetration. Condensation may occur within uninsulated masonry block and can be controlled by installing a vapor barrier on the warm side of the wall. A water emulsion asphalt paint applied to the wall surface as it is constructed is one method used to provide a moisture barrier. Moisture penetration through masonry foundation walls below grade is controlled by parging the outer face with portland cement plaster or mortar.



Cavity type brick walls with inner cavities not greater than 2 feet have withstood the strongest winds of Cyclone "Tracy" in Darwin, Australia ( 150 mph) (14). This type of wall is shown in Figure (14) and should have metal ties not less than one per two square feet of wall bonded into the mortar between walls. Cavity walls are very good for severe exposure because the cavity acts as a barrier to moisture. Rain penetration to the interior wall is practically impossible if proper flashing and weep holes are installed. To be effective certain precautions must be observed during construction.



- A. Continuous reinforced concrete bond beam. Lap bars at corners
- B. Reinforced concrete studs tied to footing
- C. Reinforcement in horizontal mortar joints
- D. Reinforced concrete footing

Figure 13. Typical methods of reinforcing concrete masonry walls. From reference (21).

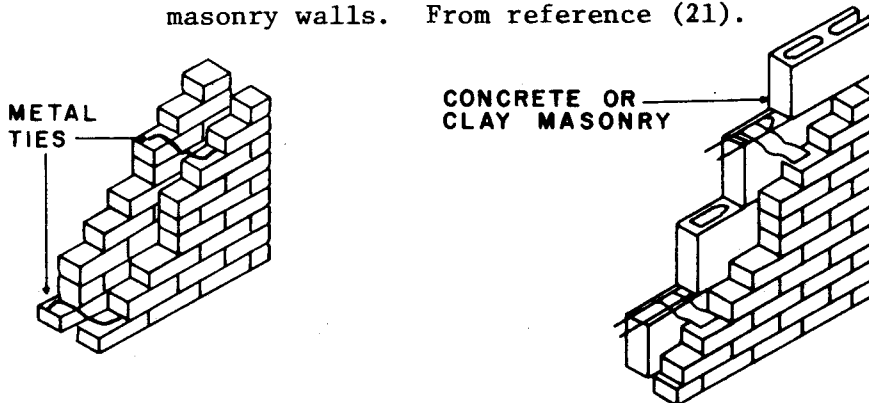


Figure 14. Cavity type walls.

The cavity must be kept free of mortar droppings and weep holes must be provided in conjunction with flashing to properly drain the cavity of any water which enters the outer wall and collects on the flashing. A vapor barrier is not required in a cavity wall where the cavity is insulated with fill materials such as water repellent vermiculite or silicon treated perlite which will not retain excessive moisture, or with rigid board materials such as glass tubes, framed glass, or foamed plastics that are at least 1" less in thickness than the cavity and are installed next to the inner wall.

Solid brick walls bonded with masonry headers are considerably less resistant to rain penetration than the metal tied cavity type walls and should not be used in this severe exposure area.

If veneer brick walls are to be used (see Figure 15), wood or plywood sheathing should be used behind it to provide protection against water penetration and also to provide additional racking resistance. Corrosion resistant metal ties should be used to tie in the brick work to the sheathing and studs to act structurally with the load bearing backup material. One metal tie should be provided for each 2 feet of wall area.

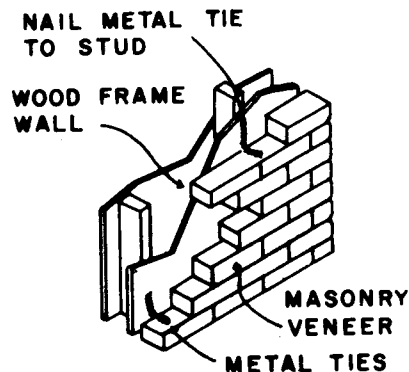


Figure 15. Veneer Brick Wall

### Pole Houses

Due to the recent enactment of the National Flood Insurance Program and the requirement that the first habitable floor level of the building be above the 100 year storm tide, a considerable number of future residential structures

built in the coastal zone will be required to be on poles (i.e. pole houses or "stilt" houses). Pole houses are a special type of wood house using pressure treated timber poles to provide elevation and structural rigidity.

In areas where erosion due to wave forces or deflation due to wind forces can cause a loss of foundation material it is wise to use pole type construction regardless. Figure 16 is of a pole house which was sitting on an 18 foot high dune system prior to September, 1975. Hurricane "Eloise" with winds of over 100 mph and an 11 foot storm tide eroded the dunes in this area some 60 feet. Other houses in the area were not built on poles and were completely destroyed while the house shown suffered only very minor damage.

Two basic types of pole house construction exist. One type, as in Figure 16, has its poles cut off at the first floor level and is tied into the first floor. A better type of construction from a structural standpoint is to have the pole system run integrally through the structure and rigidly tied into the house frame at the first floor level and the rafters (15) as illustrated in Figure 17.

Considerable literature exists on the design of pole house type construction, along with some basic structural framing plans for these types of homes in References (15), (17), (18), (19), and (20). Structure details on the various aspects of constructing these types of buildings as well as discussing the aspect of pole embedment are given in References (15), (18), and (20). The depth of pole embedment for a given house is dependent on both the house shape, exposed surfaces to the wind, wind speed and height of structure above ground. If the structure is built too close to water or is built in an area of loose sand (i.e. no vegetative cover to prevent deflation) then consideration should be given to possible loss of pole embedment cover due to erosion by wind or water. Determining pole embedment in the design of a pole house is the job of a professional engineer or architect and should not be attempted by unqualified persons. Lateral and diagonal bracing between poles to provide for wind or water forces is also a job for professional engineers or architects. Where diagonal structural bracing is to be used between poles, (in areas where design flood level is above grade), it is suggested that cable-type cross bracing be used to minimize water or wave forces on the structural framing. Additional good building practice in such situations is to use plywood sheathing on the underside of the house. Some examples of this type of practice are given in Reference (15).

Where through house type pole construction (Figure 17) is not used, it becomes necessary to properly anchor the house to the poles. Again, a professional engineer or architect should either design or certify the design of such structures to withstand the required structural loadings of the house.

It is common practice in pole house construction to have a contractor who specializes in pole type construction build the pole and beam framing for the house, while a second contractor (homebuilder) builds the house to design specifications on this framing system.

As a final testament to the structural soundness of well designed pole houses, Reference (19) discusses types of pole houses which have survived



Figure 16. Pole house which survived Hurricane Eloise.

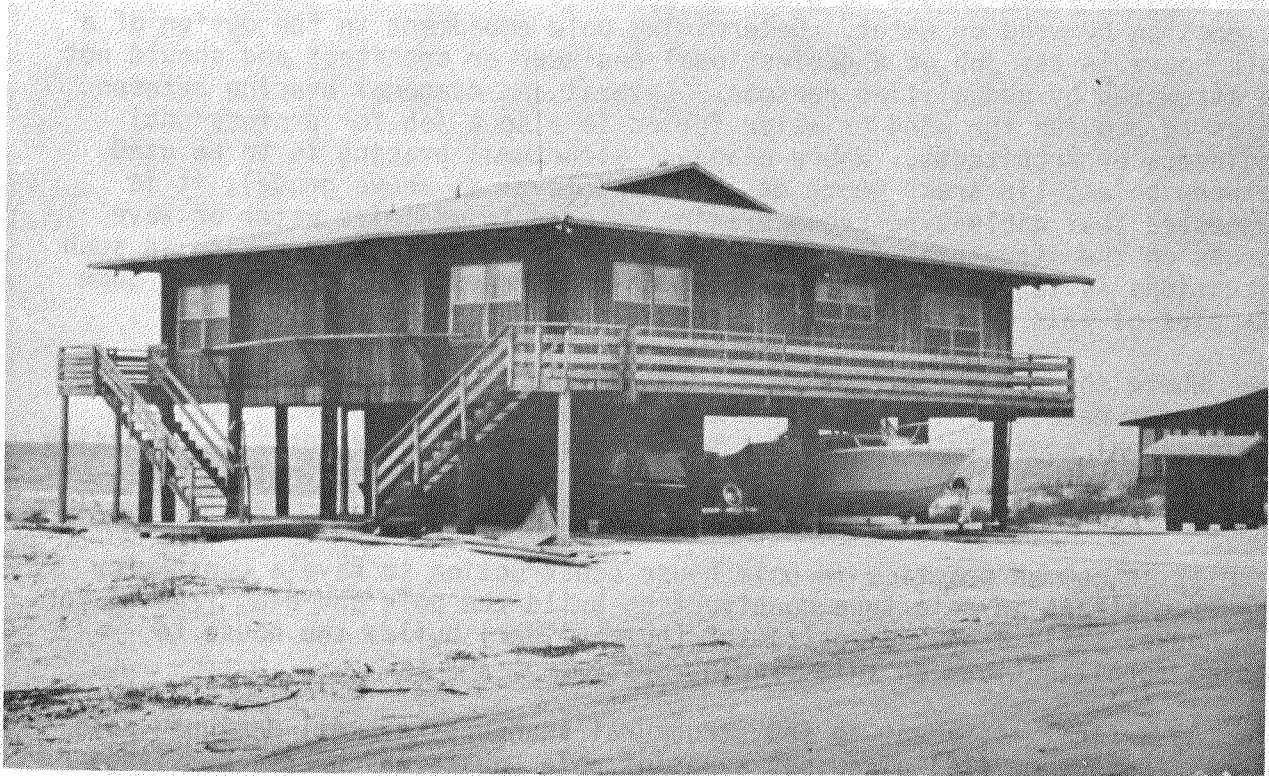


Figure 17. Pole house with integral pole - rigid frame construction.

the worst winds and water forces of Hurricane Camille with only minor damage to the structure. One family moved back into their pole house one day after Camille made its landfall.

### Special Considerations

#### Roofs

By far, the greatest damage to homes in hurricane-prone zones is due to roof losses and consequent water damage. Although any roof can be properly designed to withstand hurricane force loads, it is apparent through experience that some roof types are considerably better than others. Shapewise, it appears, hip roofs are better than gable roofs while at the same time more steeply pitched roofs fair better than low pitch roofs (3,14). Low pitch roofs act as airfoils and have higher uplift pressures exerted on their windward sides. Resisting uplift pressures becomes of more importance in design of low pitched roofs.

It appears from research on wind pressure on roofs that roofs having a pitch angle of over 40° should prevent negative (suction) pressures from developing on the windward side of roofs (2).

The majority of roofs today are framed with prefabricated roof trusses which have tension-compression web members in them. These provide a very good framing system with good structural rigidity in the plain or the trusses, although the designer should require that the trusses be sufficiently strong to withstand design wind loads.

A need for structural rigidity in the ridge framing direction is also of importance: though as has been found by the recent disastrous effects of Cyclone "Tracy", which hit Darwin, Australia in 1974 (14). An example of a building which lacked good bracing in the ridge frame direction and in the corresponding walls is shown in Figure (12). This type of failure could have been prevented by diagonal wall bracing and adequately designed structural purlins, roof sheathing (15), or a ceiling designed as a diaphragm (22,23), all of which should be adequately fastened to the wall framing.

It appears that the longitudinal bracing provided for in hip roofs may be a contributing factor to the apparent successful performance of hip roofs over the more common gable type roof systems.

Roof coverings for roofs should be selected so that high winds do not cause a loss of water shedding ability. Both wood shingles and wood shakes have resisted storm damage better than most roofing materials (15). Asphalt shingles have performed poorly in most instances, although much of this is believed due to a lack of good fastening techniques used. Information on a variety of types of covers and what constitutes good fastening for the roof covering is detailed in Reference (15). In both the U.S. and Australia, experience has shown that metal roof cladding has proved to be least acceptable and has failed in numerous instances. Again, though, the probable cause was the lack of proper fastening procedures of the metal roofing to the roof system.

Should a metal roof be used, reference (14) can provide criteria for fastening the roof in place. Proper roof cover fastening for timber roof systems is covered in reference (15).

Large overhangs (eaves) are a major cause of roof failures also. Eaves should extend out from the building a minimum distance necessary to provide drainage. Proper shading from the sun can be provided by shutters or awnings designed to be bolted down during storms.

### Doors, Garage Doors

Any doors to be used in hurricane prone zones should be structurally checked for adequacy to withstand design loading by a professional engineer or architect, or be certified by the seller as to strength under a given design wind load. This is especially true of garage doors, as experience has noted numerous failures of typical metal and wood overhead sliding doors. A typical mode of failure noted in overhead garage doors is that the wind causes the inadequately braced door to buckle thereby allowing the garage door rollers to come out of their tracks with a consequent total failure of the system. Projected missiles are also of considerable danger in a hurricane. Both doors and garage doors should be of adequate strength to prevent damage due to flying objects such as 2"x4" or tree limbs.

Additional failures to both garage and normal doors occur due to poor attachment to the framing. Usually a door is connected by two hinges and a lock. Additional fixtures such as dead bolts can be fastened onto the framing for use during hurricanes thereby providing additional rigid connection to the house framing. Note that these should be emplaced on the outside of the house since the owners of the house will usually leave the home during a severe hurricane warning.

Garage doors can have similar connections made depending on the type of door to be used. Again, due to the importance of doors in providing both protection to the interior and preventing wind blown water damage, it is desirable to have these features checked for their structural adequacy by a professional engineer or architect where building codes are lacking.

### Windows, Glass, Glazing, and Hurricane Shutters

Due to numerous window failures in past hurricanes, the South Florida Building Code (SFBC) adopted regulations concerning the fastening of windows to wall frames to ensure against the windows pulling out. This code similarly limits both the size and spacing of windows in structures and the type of glass to be used. The Metropolitan Dade County Building and Zoning Department specify that such products must be tested by a testing laboratory to SFBC design loads as a code requirement. The Building Department maintains a listing of approved products which meet SFBC specifications and will withstand high winds (120 mph, according to SFBC) provided the window systems are framed and fastened in accordance with the SFBC.

No window is safe from projected missiles such as tree limbs or similar storm debris. For this reason, it is suggested that storm shutters of adequate

strength to prevent missile damage be used with all window systems. Reference (3) notes the following:

"Storm shutters, particularly where constructed according to established standards, can be of definite value in minimizing glass breakage. For dwellings, the combination awning pull-down type offers ease of operation with reasonable possibilities of protection... The development of pull-down, roll-down, or curtain-type shutters for smaller openings appears worthy of careful consideration."

Additional damage due to wind blown water during hurricanes can be prevented by insuring that good caulking practice is used around the window system.

The South Florida Building Code provides a very good guide in the area of windows and glazing to be used. Information on properly tested products can be obtained from the Dade County Building and Zoning Department.

### Landscaping and Siting

Proper landscaping and siting of a home can be of great value to a home owner as a protective measure.

Shelterbelts of trees provide some protection against the wind if planted dense enough to break the wind force. In some studies (14,24) it has been found that tree cover can provide 10-20 percent reduction in wind speeds. Trees though, can also be detrimental if not sufficiently strong to withstand wind forces or if not pruned adequately to get rid of weak or dead limbs. Dead tree limbs projected by the wind are found to be a significant cause of home damage. Therefore, it is best to do a pruning prior to hurricane season. Also it is a good idea to tie down any trees with shallow root systems by using cables tied to the tree trunk and staked to the ground. If planting trees for a shelterbelt, use those trees with deep root systems.

Likewise, the more exposed the house, the higher the winds it will experience. Siting a house behind a sand dune on a pole type frame is preferable to building on the dune, even if the final floor elevation is at the same height. This is because the dune will deflect the winds upward and also reduce wind speeds somewhat.

The home closest to the coast or bay may provide the best scenic view, but, from a protection standpoint, has the worst exposure to severe weather. Usually the greatest damage from winds is found in the first row (most exposed) of homes. Of course, this is self evident for water and wave damage also. As wind speeds are significantly reduced when wind passes over land, as opposed to water, it pays to construct as far away from the water as is reasonable.

Vegetation prevents sand from blowing and therefore causing either wind blown sand abrasion damage, loss of foundation material (scour), or a buildup of sand against a wall causing additional structural loading that the house was not designed for. Providing good vegetation to hold sand in place during high winds should be on a coastal homeowner's checklist.

As mentioned earlier, exposure to higher winds increases with height. It is, therefore, good to keep as low a profile as possible and yet be above storm tide design level.

## VI. SUMMARY

The following items provide a checklist for home builder or home buyer considerations when building in the high hazard coastal area:

1. Check to see if your area is covered by adequate building codes. Find out what important provisions have been put into the code to protect you from wind or water damage due to poor construction practices.
2. Find out what design flood levels are for your area. You must again decide whether you wish to be more conservative than the local regulations provide for.
3. Find out what design wind loads are for your area. You must again decide whether you wish to be more conservative than the local regulations provide for.
4. Consider the details! The large majority of homes experience minor hurricane damage due to some small overlooked portion of design. With the material and references provided in this report, you should be able to check over many of these details yourself and either change the plans if you are building a home, or modifying the existing structure in case you are buying an existing home.
5. Have a design professional check out your home plans and certify them as adequate to withstand your specified hazard designs or his recommended designs. If you are buying a home, have him check out the home for possible modifications to make it structurally sound against wind or water.



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This public document was promulgated at a cost of \$ 893.20 or 22.3cents per copy, to provide information on construction of hurricane proof buildings to builders and buyers.

The Marine Advisory Program functions as a component of the Florida Cooperative Extension Service, Joe N. Busby, dean, in conducting Cooperative Extension work in Agriculture, Home Economics, and Marine Sciences, State of Florida, U.S. Department of Agriculture, U.S. Department of Commerce, and Boards of County Commissioners, cooperating. Printed and distributed in furtherance of the Acts of Congress of May 8 and June 14, 1914.

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