GUIDELINES FOR PREVISION AGAINST WIND IN HOSPITALS AND HEALTH CENTERS

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INTRODUCTION

During the design process the structural engineer must assure that the building will be able to resist the lateral loads imposed on the structure. Usually in Latin American countries the lateral loads utilized for design are those produced by earthquakes. Thanks to research conducted in the field of earthquake engineering, technological advances, and experiences during the past years it is possible to design and build structures capable to withstand most of the earthquakes that could take place in our region. However, sometimes it is the wind load instead of the seismic load that governs the design. Unfortunately, in our countries this situation is commonly ignored and the effects that could take place as a consequence of extreme wind conditions are not considered.

Hurricane season in the Northern Hemisphere extends officially from June 1 through November 30, when most favorable conditions for hurricane formation exist. Every year, during those six months, the Atlantic coast and the Caribbean islands are threatened by the hazards due to strong winds, flooding, torrential rains, storm surge, erosion, and landslides that frequently accompany hurricanes.

Because of the type of service hospitals and health centers provide, these structures are considered as essential facilities. In addition, the evacuation of certain patients in a hospital might be complicated, especially those in intensive care units or those requiring special treatment by means of sophisticated machines. Hence, it is imperative for these facilities to be design in such a way that they can continue operating before, during, and immediately after a landfalling hurricane. Figure 1 shows a hospital in the Caribbean completely

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destroyed due to the strong winds of Hurricane Gilbert in 1988, left unable to help thousands of victims resulting from this natural phenomena.

Figure 1. Hospital in the Caribbean severely damaged following a hurricane (Photograph: Tony Gibbs).

Because of its geographical position, the north of Honduras is a zone directly exposed to the hazards of hurricane winds. This document has been prepared with the objective of providing to the engineers and architects of Honduras with theoretical and practical guidelines that can be helpful for designing and building safer hospitals and health centers against wind effects.

WIND EFFECTS ON STRUCTURES

Wind flow around buildings is a rather complex process, whose simulation is difficult to obtain even with the most sophisticated mathematical models. Consequently, a detailed discussion of this phenomenon is beyond the scope of this document.

Nonetheless, for the application of most engineering problems it is sufficient to recognize that wind flow around a building depends essentially upon the size and shape of the building, angle of attack[1] of wind, the surrounding, and the roof slope. Figure 2 shows some of the effects that wind pressure has on the structures.
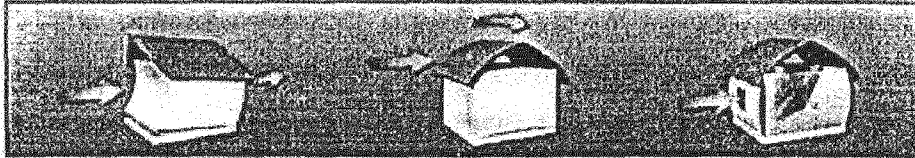

Figure 2. The house to the left shows the effect of pressure on the windward wall and suction on the leeward wall; the center house shows the effect that wind flow over the structure produces on the roof; and the house to the right shows how the openings on a building can create internal pressures that affect walls as well as the roof.

Friction produced by the terrain roughness delays the air movement at ground level, causing a reduction of the mean wind speed. For all practical effects, the wind speed at ground level is considered to be zero. As height above the ground increases, the wind speed also increases, up to a point at which the wind speed remains constant. Hence, the taller the building the more vulnerable it is against wind effects.

Sudden changes in geometric shapes of buildings can affect the wind behavior. Wind flow separates from the building at sharp edges, causing turbulence and high-localized pressures. The analytical methods used to estimate wind loads have been developed under the assumption of rectangular buildings without pronounced protrusions. When a building has irregular geometric shapes, the methods presented in the codes do not necessarily apply. In those cases, the aerodynamic effects can be so complex that it is suggested the advise of a wind engineer or that an analysis by means of a wind tunnel be performed.

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[1] Describes the wind direction with respect to the building.

The angle at which the wind strikes the building also influences the effect that the wind will have on the structure. Due to the unpredictable nature of the wind, it is assumed that the wind flows horizontally and perpendicular to the structure. The analysis and design is always performed taking into account the most critical conditions.

The surrounding also affects the way in which wind interacts with the buildings. If a hospital is located in an open area without obstructions, it will be vulnerable to wind effects than if the building were protected by dense vegetation or other buildings. On the other hand, the rougher the terrain is the greater the wind speed reduction near the ground. Such condition of high terrain roughness causes turbulence. Most building codes recognize four classes of terrain when dealing with wind loads: open water, flat open field, suburban terrain, and urban terrain with tall buildings.

Sudden accelerations of wind speed can occur for a variety of reasons. If a building is located in an area whose construction density is high, especially with tall buildings, there could be effects due to wind channeling that would result in an increment of wind speed. Abrupt topographic changes also affect the wind speed near the ground. For example, a building located atop a hill will be subjected to higher pressures than a similar building located at the bottom of the same hill. Wind acceleration produced by topographic changes depends mainly on the shape of the hill, the location of the building with respect to the hill, and the height of the building above ground.

External wind pressures are those pressures acting on the exterior surfaces of a building. If the pressure is exerted in the direction toward the surface, the pressure is said to be positive. On the other hand, if the pressure is exerted away from the surface, the pressure is considered to be negative.

It is possible for wind to enter a building through windows, doors, or any opening either existing or produced by wind-borne missiles. When this happens, internal pressures are generated which could affect considerably the structural integrity of the building. The algebraic signs of the internal pressures

are determined in the same way as the external pressures. Figure 3 shows two structures subjected to external and internal pressures, both positive and negative.
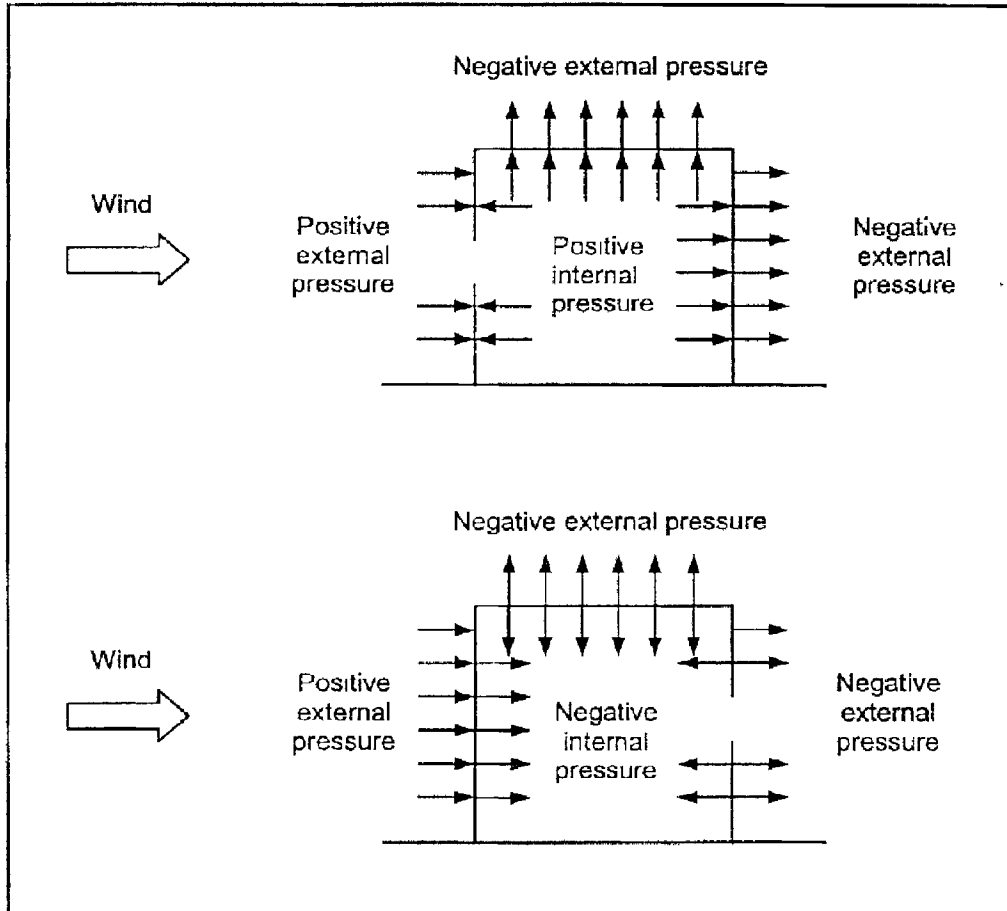

Figure 3. External and internal wind pressures.

The slope of the roof also affects the wind/structure interaction. Gable roofs with slopes less than 35 degrees can cause positive or negative external pressures on the windward side, while on the leeward side the external pressures will always be negative. When internal pressures are generated during a hurricane, it is possible for external and internal pressures to combine, increasing considerably the wind loads and causing total or partial detachment of the roof system.

During a storm, the wind loads generated by external and internal pressures must be transferred from the roof to the exterior walls and columns, and finally to the foundation (Figure 4). A building can be seriously damaged or totally destroyed if the wind energy is not properly transferred to the ground. Therefore, it is most important to provide the building with (1) structural elements capable to withstand the wind loads, and (2) adequate connections capable to transfer the loads generated by the wind
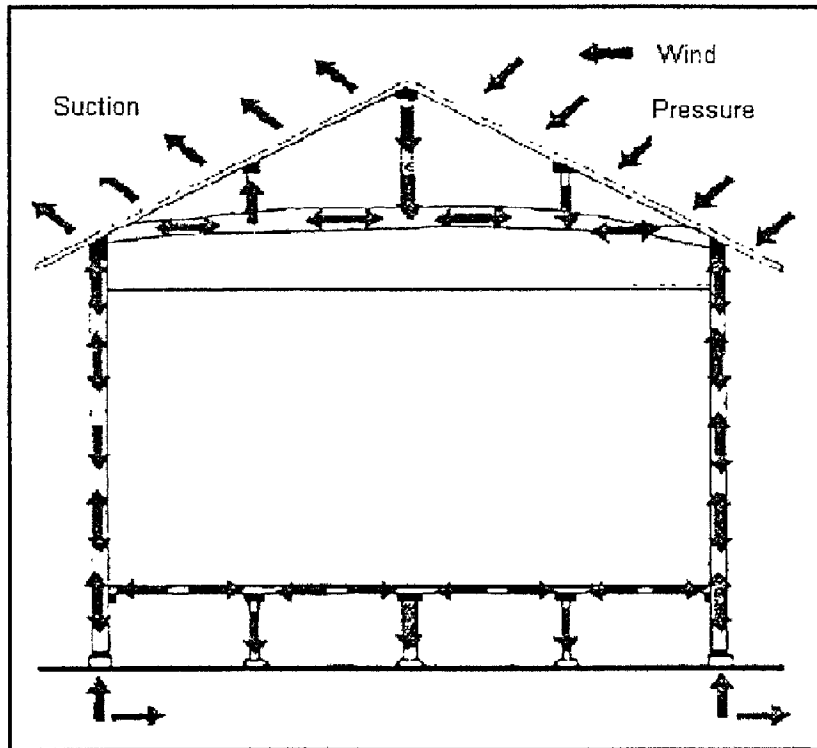

Figure 4. Continuous load path.

PHILOSOPHY OF WIND LOAD DESIGN

Wind is a term utilized to describe the air in motion, and it is usually applied to horizontal motion of the atmosphere. Due to its nature, measuring wind speed cannot be done the same way the velocity of an object in motion is measured. The equation: velocity equals distance divided by time simply does not apply. That is why for years engineers and architects utilized the definition of wind

speed known as *fastest mile*. Fastest mile is the time required by a volume of air to travel a horizontal distance of 1 mile through an anemometer[2].

Sudden changes of wind speed in the form of high-speed accelerations are referred to as *wind gusts*. Wind gusts have averaging times that range approximately between 2 seconds and 10 seconds. Thanks to technological improvements, newer and better anemometers have been manufactured that allow measuring wind speeds averaged in shorter time intervals. Consequently, now it is possible to measure wind gusts in a more precise way. Since the structures are affected primarily by wind gusts (rather than wind averaged over a long period of time), most building codes in the United States have adopted the 3-second wind speed as the design wind speed to calculate wind pressures on structures.

In the case of hurricane winds, wind speeds are generally reported measured in a 1-minute averaging time. These wind speeds are commonly known as sustained wind speeds and are the ones utilized in the Saffir-Simpson hurricane scale. However, the 3-second wind speed shall be used when designing structures subjected to hurricane winds.

One of the most widely accepted wind codes in the United States was developed by the American Society of Civil Engineers, which published its latest version (ASCE 7-98) in the year 2000. ASCE 7-98 is the result of years of research in the field of wind engineering in the best universities and research centers of the United Stated and worldwide. The equations and parameters utilized by ASCE 7-98 have been derived with a sound theoretical base and have been – and constantly are – verified and calibrated through experiments in state-of-the-art laboratories. The International Building Code (IBC 2000) recently adopted ASCE 7-98 for the determination of wind loads.

The procedure to calculate wind loads described by ASCE 7-98 is applicable to determine the minimum wind loads of main wind force resisting systems and

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[2] Anemometer is a device utilized to measure wind speed and wind direction.

components and cladding of buildings and other structures (billboard signs, storage tanks, chimneys, communication towers) meeting with the following criteria:

a) The building or other structure has a regular shape, such as the one defined by ASCE 7-98, and
b) The building or other structure does not have response characteristics of that make them susceptible to aeroelastic phenomena such as buffeting, vortex shedding, or flutter; or its location does not make it vulnerable to other types of phenomena requiring special attention.

The procedure presented by ASCE 7-98 takes into account the magnification effect caused by wind gusts in resonance with vibrations in the along-wind direction of buildings and other flexible structures. When the building or other structure (1) does not comply with the requirements previously described, (2) has an unusual shape, or (3) has an unusual response characteristic, it shall be designed (1) utilizing publications dealing with such effects or (2) based on wind tunnel modeling.

The following is a summary of the general procedure of ASCE 7-98 to determine the minimum wind loads. This summary is not intended to replace the ASCE 7-98 code, but to present the necessary steps to calculate wind pressures. The application of ASCE 7-98 requires the use of figures and tables not included in these guidelines

1. Determination of the basic design wind speed (V). The maximum annual wind speeds expected vary depending on the region and country. Therefore, it becomes necessary that a basic design wind speed for the Republic of Honduras be established through a statistical study utilizing wind speed records. If there were not enough wind speed records the basic design wind speed could be established based on existing wind speed record combined with judgment from experienced engineers and meteorologists in Honduras.

2. Calculation of velocity pressure (q_z). The basic design wind speed (V) is transformed to a velocity pressure (q_z) using a mathematical expression

derived from the Bernoulli equation ($\frac{1}{2}\rho V^2$) and applying a series of correction factors. The expression for the metric system is:

$$q_z = 0.004827 K_z K_{zt} K_d V^2 I \quad (kg/m^2)$$

where K_z denotes the exposure factor, K_{zt} denotes the topographic factor, K_d denotes the wind directionality factor, V denotes the basic design wind speed (in kilometers per hour), and I is the importance factor.

The exposure factor (K_z) depends upon the terrain characteristics and the height at which the wind pressure is calculated. This factor is utilized to adjust the wind speed as a function of height, as well as the friction effect caused by the terrain roughness. Four classes of terrains have been defined: A, B, C, y D, where D are flat, unobstructed areas exposed to wind flowing from over water, C are open terrains with scattered obstructions, B are urban or suburban areas, and A are large city centers with at least 50% of the buildings having a height in excess of 21 meters. The topographic factor (K_{zt}) takes into account changes of topography of the surroundings where the structure is located, such as hills and ridges. The wind directionality factor (K_d) is utilized because of the small probability that the maximum winds and the maximum pressure coefficients occur simultaneously in a specific direction. The factor of importance (I) is utilized to adjust the level of structural reliability of a building or other structure to be consistent with a building classification based on the nature of occupancy. The building categories vary from I to IV, where category I represents buildings and other structures with a low risk to human lives in the event of failure, while categories III and IV are buildings and other structures considered essential facilities that require a greater factor of safety.

Once all correction factors have been applied, the velocity pressure (q_z) as a function of height can be obtained. This way, it is possible to calculate wind pressures for any given height of the building.

3. Main wind force resisting system versus components and cladding. It is necessary to design both the elements of the main wind force resisting system and the elements considered components and cladding. The main wind force resisting system is the group of structural elements designed to provide support and stability to the structure in a global manner, while components and cladding are those elements of the building that do not qualify as part of the main wind force resisting system. Examples of components are fasteners, purlins, girts, roof trusses, and any element that transfers loads to the main wind force resisting system. Components receive wind loads directly or from cladding. Cladding consists of elements utilized to enclose the building and receive wind loads directly, which then transfer to the main wind force resisting system. Examples of cladding include wall coverings, curtain walls, roof coverings, exterior windows, and exterior doors.

Depending on whether the main wind force resisting system or components and cladding is being designed, certain specific parameters need to be determined such as the gust factor and pressure coefficients. That is why it is necessary to establish which of the two systems is going to be designed.

4. Determination of the wind gust effect factor (G). To calculate the gust effect one must determine if the building is rigid or flexible. A rigid building is one that is not sensitive to the wind actions (that is, a building whose natural frequency is greater than 1 Hz or whose height is less than four times its least horizontal dimension). On the other hand, a flexible building is one that is sensitive to the wind actions (that is, whose natural frequency is less than 1 Hz).

The wind energy of gusty winds is smaller in frequencies greater than approximately 1 Hz. Therefore, resonance in most buildings with natural frequencies greater than 1 Hz would be sufficiently small so that can be neglected. Hence, the gust effect factor for rigid buildings may be taken as 0.85.

For flexible buildings, the gust effect factor shall be determined by a rational analysis that incorporates the dynamic properties of the main wind force resisting system. ASCE 7-98 presents one of these procedures but there are also other procedures available from the technical literature.

The method described by ASCE 7-98 is easy to apply since only requires information about exposure categories, basic design wind speed, building geometry, natural frequency of the building, and damping ratio of the building. These guidelines include a spreadsheet that can be utilized to calculate the gust effect factor for flexible buildings in a systematic way.

5. Determination of external and internal pressure coefficients (C_p, GC_p, and GC_{pi}). Pressure coefficients have been determined and calibrated through wind tunnel experiments under laminar flow conditions and full-scale testing at field laboratories under real conditions. Please note that pressure coefficients for main wind force resisting systems, GC_{pi}, and components and cladding, GC_p y GC_{pi}, already include the gust effect factor and that is why they are shown within parenthesis.

External pressure coefficients are determined by means of tables and figures and depend upon the geometry and area of the surface that is being analyzed. Internal pressure coefficients depend upon the type of enclosure of the building.

6. Calculation of wind pressures.

Wind pressures (p) on the main wind force resisting system, in kilograms per square meter, are given by:

$$p = qGC_p - q_i(GC_{pi})$$

where q denotes the velocity pressure, G denotes the gust effect factor, C_p denotes the external pressure coefficient, q_i denotes the velocity pressure

evaluated at mean roof height, and GC_{pi} denotes the internal pressure coefficient.

Wind pressures (p) on components and cladding, in kilograms per square meter, are given by:

$$p = q_h [(GC_p) - (GC_{pi})]$$ buildings with h ≤ 18 meters

where h denotes the mean roof height, q_h denotes the velocity pressure evaluated at mean roof height, GC_p denotes the external pressure coefficient, and GC_{pi} denotes the internal pressure coefficient.

$$p = q(GC_p) - q_i(GC_{pi})$$ buildings with h > 18 meters

where h denotes the mean roof height, q denotes the velocity pressure, GC_p denotes the external pressure coefficient, q_i denotes the velocity pressure evaluated at mean roof height, and GC_{pi} denotes the internal pressure coefficient.

ASCE 7-98 also includes a section for the calculation of wind pressures on billboard signs. It is extremely important for billboard signs to be properly designed against strong winds, otherwise they can become wind-borne missiles during a hurricane. A billboard sign flying at over 200 kilometers per hour can cause serious damage even to structures properly designed to resist hurricane winds.

For the specific case of hospitals and health centers in Honduras, it is possible to simplify the procedures previously described to determine the wind pressures directly from a table. The simplification requires the following conditions to be met:

- The roof slope should be less than 10°.
- The mean roof height should be less than 12 meters.
- The shape of the building should not be irregular.
- The building should not be sensitive to the wind (should not be flexible).

Because hospitals and health centers are considered essential facilities that require to be fully functional immediately after a natural phenomenon, and due to its nature of occupancy – where a large number of people congregate in one area at a specific time – a factor of importance of 1.15 will be used. Additionally, the buildings are assumed partially enclosed, which is the most common situation.

The procedure is as follow:

1. Determine the basic design wind speed.
2. Determine the terrain exposure.
3. For the main wind force resisting system: read wind pressures from Table 1. Wind pressures shall be applied perpendicular to the surface. Wind pressures shall be applied simultaneously, with the combined net pressures of the walls applied to all windward walls and the net pressures of the roof applied to all surfaces of the roof.
4. For components and cladding: read wind pressures from Table 2. These net design pressures shall be applied to all exterior surfaces.

Table 1. Wind pressures for main wind force resisting system.

WIND PRESSURE (kg/m^2)									
Location	**Basic Design Wind Speed, V (kph)**								
	135	**145**	**160**	**175**	**190**	**210**	**225**	**240**	**255**
Roof	-120	-135	-165	-195	-230	-270	-315	-360	-410
Wall	75	90	110	125	150	180	205	235	265

Notes:

1. Wind pressures from Table 1 represent the following:
   Roof – Net pressure (sum of external and internal pressures) applied perpendicular to all surfaces of the roof.
   Wall – Combined net pressure (sum of windward and leeward pressures, external and internal) applied perpendicular to all surfaces of the windward wall.

2. The values of Table 1 are based on a regular topography (K_{zt} = 1). When the hospital or health center is located on a hill, ridge, or escarpment, the topographic factor (K_{zt}) shall be computed according to ASCE 7-98 and the values of Table 1 shall be multiplied by this factor.

3. The values of Table 1 are valid for exposure B. For exposure C, multiply the values of Table 1 by 1.40; for exposure D, multiply the values of Table 1 by 1.66.

4. Positive and negative signs indicate pressures directed toward and away from the exterior surface, respectively.

Table 2. Wind pressures for components and cladding.

Location	Zone[7]	Area (m²)	WIND PRESSURE (kg/m²) — Basic Design Wind Speed, V (kph)																
			85		90		100		110		120		130		140		150		160	
Roof	1	0.93	+65	-105	+65	-120	+80	-150	+100	-180	+120	-210	+135	-245	+155	-285	+180	-325	+205	-370
		1.86	+65	-105	+65	-120	+75	-145	+95	-175	+115	-205	+130	-240	+150	-280	+175	-320	+200	-365
		9.30	+65	-100	+65	-115	+70	-135	+90	-170	+100	-200	+120	-230	+135	-265	+160	-310	+180	-350
	2	0.93	+65	-160	+65	-180	+80	-225	+100	-265	+120	-320	+135	-370	+155	-430	+180	-500	+205	-565
		1.86	+65	-150	+65	-160	+75	-205	+95	-240	+115	-290	+130	-340	+150	-395	+175	-450	+200	-510
		9.30	+65	-115	+65	-125	+70	-155	+90	-185	+100	-225	+120	-260	+135	-300	+160	-350	+180	-395
	3	0.93	+65	-230	+65	-255	+80	-315	+100	-380	+120	-450	+135	-530	+155	-615	+180	-705	+205	-805
		1.86	+65	-190	+65	-215	+75	-265	+95	-320	+115	-380	+130	-450	+150	-515	+175	-595	+200	-675
		9.30	+65	-115	+65	-125	+70	-155	+90	-185	+100	-225	+120	-260	+135	-300	+160	-350	+180	-395
Wall	4	0.93	+105	-115	+120	-125	+150	-155	+180	-185	+210	-225	+245	-260	+285	-300	+325	-350	+370	-395
		4.65	+100	-105	+115	-120	+135	-145	+160	-175	+190	-210	+230	-245	+260	-285	+300	-325	+340	-370
		46.5	+90	-95	+95	-105	+120	-130	+145	-155	+170	-185	+200	-215	+230	-245	+265	-285	+300	-325
	5	0.93	+105	-130	+120	-150	+150	-185	+180	-225	+210	-265	+245	-310	+285	-355	+325	-410	+370	-465
		4.65	+100	-120	+115	-130	+135	-160	+160	-190	+190	-230	+230	-270	+260	-315	+300	-355	+340	-405
		46.5	+90	-95	+95	-105	+120	-130	+145	-155	+170	-185	+200	-215	+230	-245	+265	-285	+300	-325

Table 2. Continued.

Notes:

1. Wind pressures from Table 2 represent net pressures (sum of external and internal pressures) applied perpendicular to all surfaces.

2. The values of Table 2 are based on a regular topography ($K_{zt} = 1$). When the hospital or health center in located on a hill, ridge, or escarpment, the topographic factor (K_{zt}) shall be computed according to ASCE 7-98 and the values of Table 2 multiplied by this factor.

3. The values of Table 2 are valid for exposure B. For exposure C, multiply the values of Table 1 by 1.40; for exposure D, multiply the values of Table 1 by 1.66.

4. Interpolation is permitted for values between tributary areas.

5. Positive and negative signs indicate pressures directed toward and away from the exterior surface, respectively.

6. All elements of the components and cladding shall be designed for positive and negative pressures of Table 2.

7. The zones are:
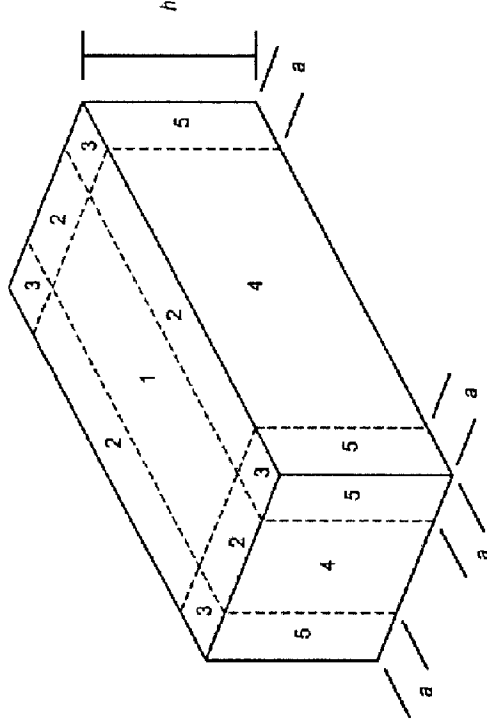
Where a equals 10% of the least horizontal dimension or $0.4h$, the smallest of the two values, but not less than 4% of the least horizontal dimension or 1 meter; h is the mean roof height (in meters).

WIND SPEED MAP FOR HONDURAS

A wind speed map indicates the basic design wind speeds of a region with isotachs[3]. The objective of the map is to facilitate the engineer or architect the selection of the basic design wind speed depending on the geographic zone where the structure is to be designed or analyzed.

The basic design wind speeds are obtained through statistical studies and opinions supplied by a panel of experts in the field of wind engineering. These design wind speeds are usually associated with a probability of 2% that they will be equaled or exceeded (50-year mean recurrence interval). In addition, these wind speeds are given in standard conditions according to international wind provisions: at 10 meters above ground in open terrain with scattered obstructions (exposure C as defined by ASCE 7-98).

The map must clearly state the wind speed averaging time that represents: fastest mile, sustained wind speed, or 3-second wind speed. The map in ASCE 7-98 utilizes 3-second wind speed. It is advisable that the wind speed map for Honduras also utilizes 3-second wind speed to be consistent with ASCE 7-98.

To make the map, 2 types of wind speeds need to be identified: non hurricane and hurricane. For non-hurricane winds, records with information about direction and speed are required. At least 10 years of wind records are recommended in order to achieve results with a greater level of confidence. To make the map of the entire Republic of Honduras it is necessary to obtain wind records from different locations of the country.

Maximum annual wind speeds need to be analyzed using a statistical distribution that approximates extreme wind conditions. The technical literature refers to 3 distributions with these characteristics: Gumbel (Type I), Fisher-Typpett (Type II), and Weibull. There are arguments among experts as to which distribution approximates best extreme wind conditions. Nonetheless, in

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[3] Isotachs are lines joining points of equal wind speed.

general the Gumbel is considered the best distribution for extreme winds and the Weibull for hurricane winds.

When there are not enough wind records (less than 10 years of records), it is possible to utilize a modified version of the Gumbel distribution. In this case, monthly records rather than yearly records would be used. It is important to mention that an analysis with a small number of wind records may result in *sampling errors*, which may be as high as 20%. Hence, the smaller the number of wind records, the greater conservatism needs to be exercised when developing the wind speed map.

The basic design wind speed for hurricane-prone regions (north of Honduras) present a special problem. Since Honduras is affected by hurricanes with a relatively low frequency (once every 6.2 years, on average), the number of records of hurricane winds is insufficient to perform a suitable statistical analysis. This problem can be handled through Monte Carlo simulation. The simulation involves a mathematical model that reproduces a wind field based upon certain parameters (radius of maximum winds, hurricane forward velocity, minimum central pressure, and Coriolis) defining a hurricane. These parameters may be inferred from historical hurricanes of the region. The simulation requires a sufficiently large number of iterations in order to obtain a reliable database that can be utilized to develop a hurricane wind speed map for the north region of Honduras.

A local commission formed by engineers, architects, and experts in the area of wind should discuss the final result of the statistical analysis and establish, jointly, the wind speed map for the Republic of Honduras.

CONSTRUCTION DETAILING AND REINFORCEMENT

The key for a hospital or health center to be able to survive the unpleasant visit of a hurricane is simple: prevent wind and water from entering the building. In order to achieve this objective. all structural elements as well as non-structural

elements need to withstand the wind pressures. This section discusses the most susceptible zones of a building during a hurricane and advances some mitigation measures to reduce the vulnerability of hospitals and health centers against hurricane winds.

The wind effects discussed in the previous section will have different impacts on structures depending upon their geometry, roof type, roof slope, construction materials utilized, and the condition of the structure, to name a few. Likewise, there are certain zones of the building that, for a variety of reasons, are more vulnerable against wind actions (Figure 5). It is these zones where the highest suctions are produced due to vortices generated by high-localized pressures. If the engineer or architect recognizes these zones, it is possible to design a new structure or retrofit an existing one in such a way that the structure and its components can withstand the high pressures generated during a tropical storm.
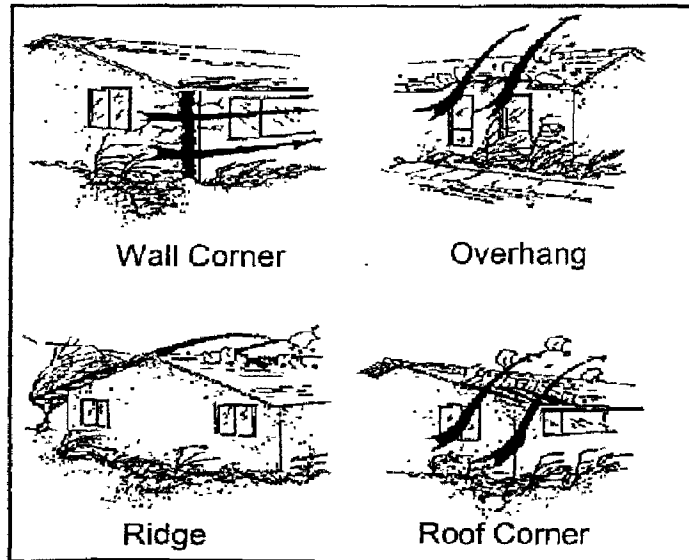
Figure 5. Most vulnerable zones of a building against strong winds.

Roofs

The most common type of failure during a hurricane begins on the roof. On the roof corners and ridges high-localized pressures generate due to the wind-structure interaction. As a consequence, part of the roof covering in these zones is detached by the wind, exposing the interior of the building and other parts of the structure to the wind, wind-borne missiles, and rain that generally accompanies a hurricane. To prevent this from happening it is necessary to provide an adequate anchorage to the roof covering. In Honduras the type of roof covering most commonly used is the galvanized steel sheet, which is screwed into the roof structure. The steel sheets need to resist gravity loads as well as wind loads produced by external and internal pressures (which usually act upward during a hurricane, resulting in separation and launching of complete roof systems). The roof sheeting should be heavy, with a minimum width of 0.5 mm when they are made of steel and a minimum width of 0.9 mm when they are made of aluminum. The asbestos cement sheets are not recommended because they are fragile and more susceptible to be damaged by wind-borne missiles. It becomes necessary that roof sheeting providers emphasize their recommendations regarding the connection of their manufactured sheets to the supporting beams. The use of screws is preferred over nails, since screws have a greater capacity to fasten the sheets against pullout. Figure 6 shows the areas of the roof requiring a greater concentration of fixings since those areas are subjected to higher wind pressures.
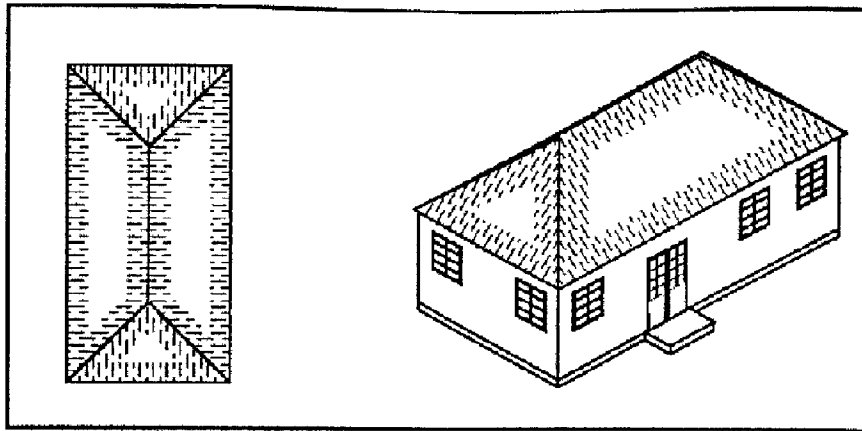
Figure 6. Typical distribution of those areas of roof coverings requiring a greater concentration of fixings (Illustration: Tony Gibbs).

Continuous contact with weather actions tends to reduce the resistance capacity of screws and nails, often resulting in removal of roof sheathings even under normal[4] conditions. When screws and nails wear out, the roof system is no longer safe against future tropical storms. To ensure proper roof anchoring, periodic inspection of screws and nails is warranted to make sure that rust has not developed and that all fixings are in place and adequately secured.

Structural elements of the roof also need to be securely anchored between them in order to resist wind pressures. Galvanized steel channels embedded in reinforced concrete beams provide an excellent resistance capacity against wind pressures because of the restricting condition to move horizontally and vertically. This is important because in addition to gravity loads (downward) and wind loads (lateral and downward), the roof structure must be able to resist uplift forces imposed by the wind. In case of wooden roof structures, the structural elements should be fastened preferably with screws; if nails are used, these should be galvanized.

Additionally, wooden members should be secured utilizing hurricane clips made out of galvanized steel (Figure 7). These clips help transfer the loads and provide the roof system with the required capacity against uplift forces and

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[4] Normal conditions are referred to as effects of non-hurricane winds, which may reach wind speeds up to 120 kilometers per hour (sustained wind speed).

hence, protect the roof from being removed and thrown away. The cost of hurricane clips is relatively low, their installation is simple, and their use increases considerably the capacity of the structure to withstand hurricane winds.
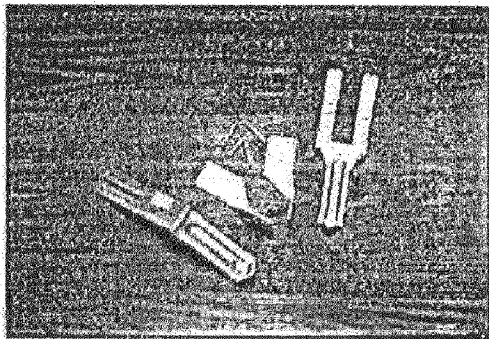

Figure 7. Samples of metal connectors used to secure timber elements.

End walls of buildings with gable roofs are subjected to high wind pressures during hurricanes. This type of roof requires additional reinforcement to guarantee that the roof system can withstand the lateral forces. Figure 8 shows an example of reinforcing by bracing the trusses of a wooden roof system with 2"x4" that are 8 feet long or more.
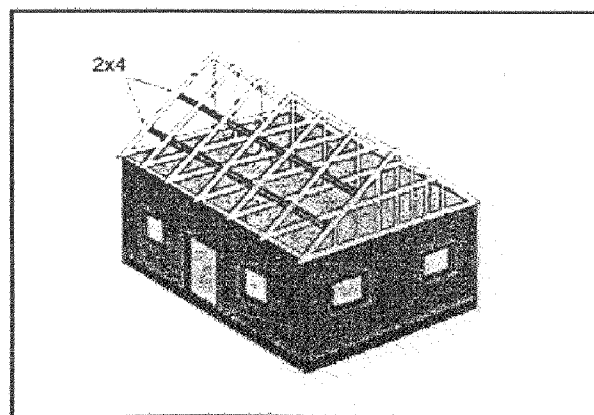
Figure 8. Gable roof reinforced with 2"x4"x8' elements. The distance between reinforcing elements should no be greater than 1.20 m.

Even though wood as a material for structural elements in Honduras is rarely utilized anymore, certain recommendations about its use have been incorporated in this document because (1) there is always the possibility of using wood as a material in the future, and (2) there are existing hospitals and health centers built out of wood that may – and should – be retrofitted in order to provide them with the necessary capacity to resist high wind pressures.

Overhangs

Overhangs, frequently utilized in constructions in Honduras and Central America, are also one of the weak spots of roof systems, making them vulnerable against wind actions. External pressures concentrate underneath overhangs, contributing to the separation of part – and sometimes all – of the roof system. The use of overhangs should be avoided when possible, especially for health centers located in coastal zones in the north of Honduras. When the use of overhangs is inevitable, then it is recommended that overhangs (1) be isolated from the roof structure so that an eventual overhang failure does not compromise the structural integrity of the roof, (2) be as short as possible, and (3) be protected with a metal flashing[5] in the perimeter of the roof between the roof sheathing and the purlins (Figure 9).

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[5] Flashing is a component utilized to seal the roof system in those areas where roof sheathing (e.g., steel sheets) are interrupted or end. Flashings are constructed in galvanized steel, aluminum, copper, or PVC.
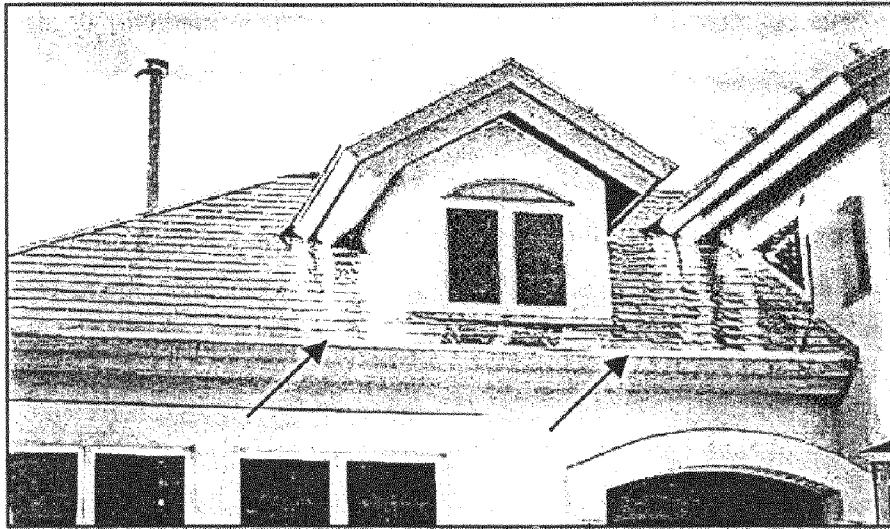
Figure 9. The main purpose of the metal flashing is to prevent the wind from entering between the roof covering and the exterior beam, which would initiate the separation of the roof covering creating an initial point of failure for the entire roof system.

Walls

Walls in Honduras are built primarily in concrete and masonry. When reinforced with steel, concrete and masonry walls provide an excellent resistance against hurricane winds; without steel reinforcement, their resistance capacity against hurricane winds reduces dramatically. In a few regions of Honduras, walls are also made out of wood. Wooden walls are capable to resist hurricane winds as long as careful attention is given to their design as well as during their construction phase.

The connection details between walls-roof and walls-foundation should not be overlooked. A building can only withstand wind loads when it successfully transfers such loads to the ground through a continuous load path (Figure 4). To ensure this, it is imperative that all structural elements be adequately interconnected. Each structural element of the roof system should be properly fastened and the roof should be firmly anchored to the exterior walls. When connections are not adequate, roofing systems tend to be completely detached and thrown away, turning into dangerous wind borne missiles that can impact adjacent buildings.

In the case of concrete and masonry construction with metallic roof sheathing, the wall-roof connection is automatically achieved by embedding the purlins into the bond beams. Existing buildings with simply supported purlins require proper fixing of the purlins into the walls. In wooden constructions, these connections are better accomplished utilizing the hurricane clips previously discussed. An adequate wall-foundation connection is necessary to transfer the loads to the ground through the foundations.

Windows and doors

Windows and doors are not part of the main wind force resisting system; however, their performance during a hurricane can be the difference between survival and destruction of a building. Although the probability of a window or door to be impacted by flying debris (elements from another building, tree limbs, stones) is very low, such an event could have serious consequences. Figure 10 shows a wooden element, probably a 2"x4", launched by the wind at such high speed that went through a palm tree. Should this had happened to a window, door, or even a wall, the interior of the building would be exposed to the wind, generating positive internal pressures. These internal pressures would probably contribute to severely damage the already weak structure, causing additional damage to the furniture and equipment (usually quite expensive in hospitals) located inside the building. And since hurricanes are frequently accompanied by rain, water would enter the building preventing it from functioning once the storm has ceased.

Figure 10. Hurricane winds may reach such high wind speeds that loose objects or structural elements, especially roof elements, are frequently turned into dangerous missiles. The picture shows a wooden element, probably a 2"x4" from a roofing system, that went through a palm tree.

There are windows specially designed and built to withstand hurricane winds. These special windows must comply with the requirements of the American Society for Testing Materials (ASTM), which include but are not limited to ASTM E 1233 (wind resistance) and ASTM E 1886 (impact resistance). These windows are commercially available in a great variety of sizes and colors.

It is recommended to protect the windows from flying objects, whether they are design against hurricane winds or not. Window shutters are the most efficient way to protect the windows. Window shutters are installed on the exterior face of the windows and are designed to withstand high pressure and missile impact from hurricane winds. There are several styles of window shutters, including accordion shutters, removable storm panels, rolling shutters, and Bahamas shutters (Figures 11, 12, 13, and 14) available in galvanized steel, aluminum, and even PVC.
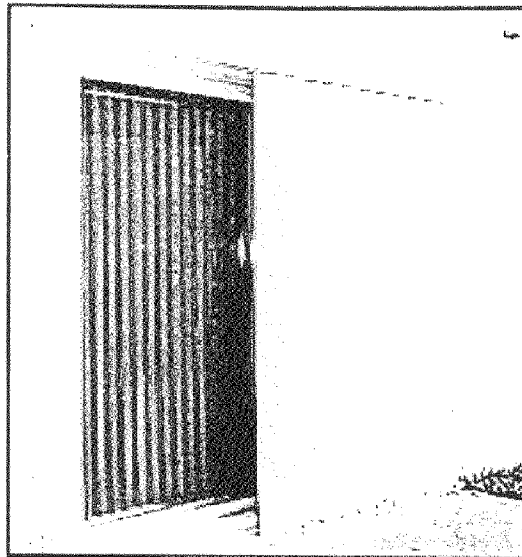
Figure 11. Accordion shutters.
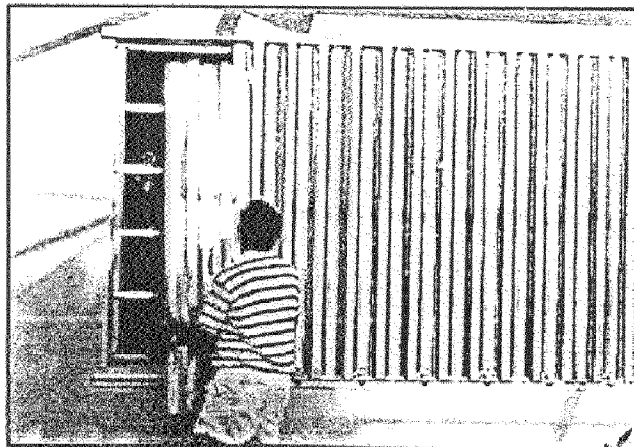
Figure 12. Removable storm panels.
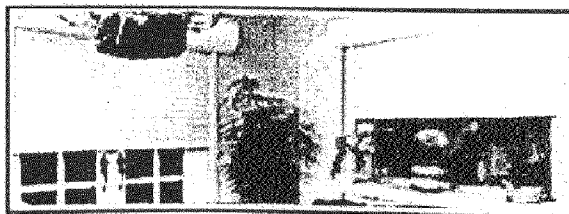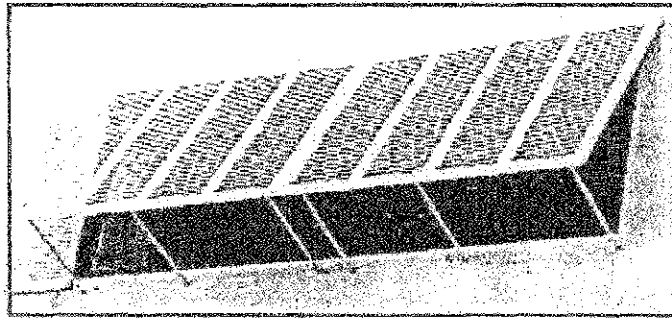

Figure 13. Rolling shutters.

Figure 14. Bahamas shutters

The most commonly used storm shutters are galvanized steel removable panels. This type of shutter should not be anchored directly to the window frame (wooden frames), because the purpose of the shutter is to protect the windows and their frames against wind borne missiles (Figure 15). Instead, it is better to install a permanent steel plate on the exterior wall so the panels can be attached quickly when a hurricane warning is issued (Figure 16). Additionally, metal panels have the advantage that can be utilized again in the event of future storms.
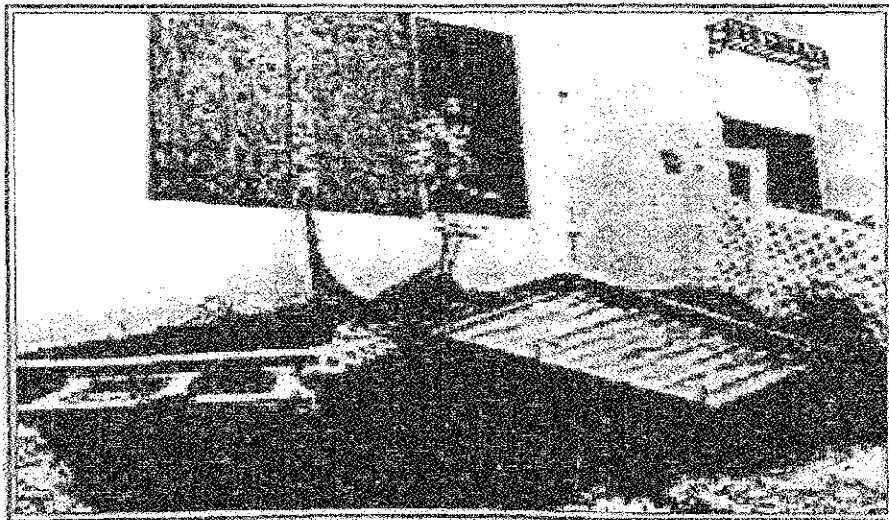
Figure 15. The window shutter of this house was completely removed because its frame did not resist the hurricane winds.
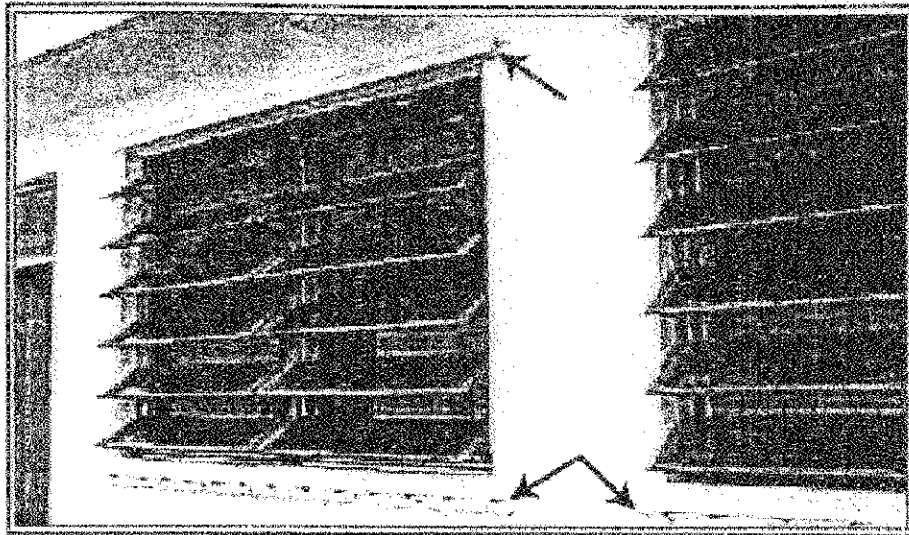
Figure 16. This picture shows the permanently attached angles to which the removable panels would be fixed. The installation of these angles should be done according to specifications supplied by the manufacturer. Usually screws are placed every 15 cm and expansion plugs are utilized.

Sometimes wooden shutters are utilized (typically plywood sheets). Although plywood sheets are less resistant than commercially manufactured shutters, they represent a more economical alternative (short term). This practice is commonly utilized to reinforce, just a few hours prior to the hurricane landfall, windows and doors of those buildings that do not have window shutter systems. New plywood sheets properly installed can provide an acceptable level of protection. However, weathered plywood sheets (which is usually the case) or inadequately installed plywood sheets will probably not withstand hurricane winds and may even become dangerous missiles during the storm.

Doors should also be designed to resist hurricane winds. There is a wide variety of styles commercially available. As a more economical alternative, existing doors can be protected with shutters or reinforced with hinges and screws specially designed to resist high wind pressures.

GENERAL RECOMMENDATIONS

Hospitals and health centers are essential facilities that (1) congregate a large number of people in one area at a particular time, and (2) require to keep functioning immediately after a natural phenomenon. In addition, many of the apparatuses utilized to treat patients with health problems are extremely expensive and sensitive, and frequently difficult to replace. Hence, an investment of a small fraction of the total cost of the hospital to guarantee the life of its occupants and its sophisticated equipment is more than justified.

Taking into consideration these facts and the different alternatives discussed in this document, it is preferable that the construction of hospitals and health centers include reinforced masonry walls, reinforced concrete beams and columns, and a roofing system composed of galvanized steel channels and metal sheathing (galvanized or enamel) properly anchored with screws. It is also recommended the use of windows and doors designed to withstand hurricane winds and steel window shutters.

It is important to realize that wooden construction is perfectly feasible as long as (1) the wood is treated with chemicals against insects, (2) the wood is protected with a waterproof product, (3) the elements are adequately anchored (preferably with screws), (4) hurricane clips are utilized to secure the structural elements, and (5) a continuous load path is provided. However, wooden structures require a great deal of attention during design and construction, as well as meticulous maintenance once they have been built. Figures 17 and 18 show two houses built out of wood and exposed to hurricane winds of similar intensities; one of them did not resist the high wind pressures (Figure 17), while the other one suffered no damage at all (Figure 18).
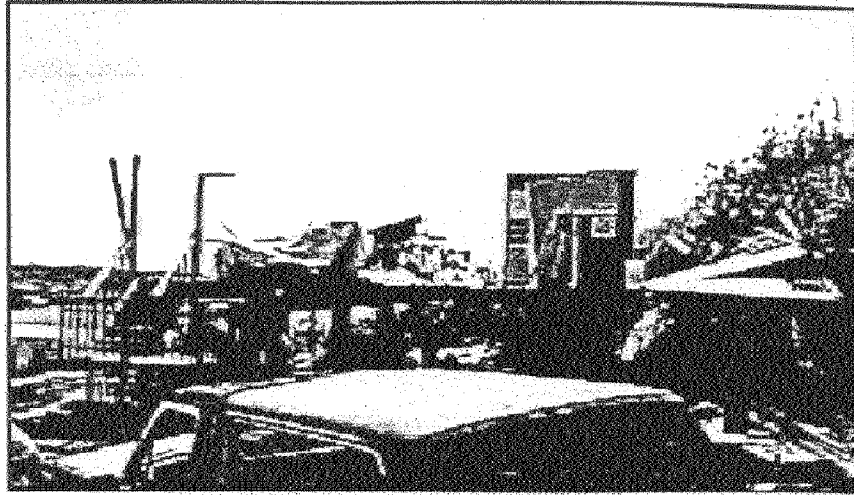
Figure 17. This wooden house was completely destroyed during Hurricane Georges in Puerto Rico, 1998.
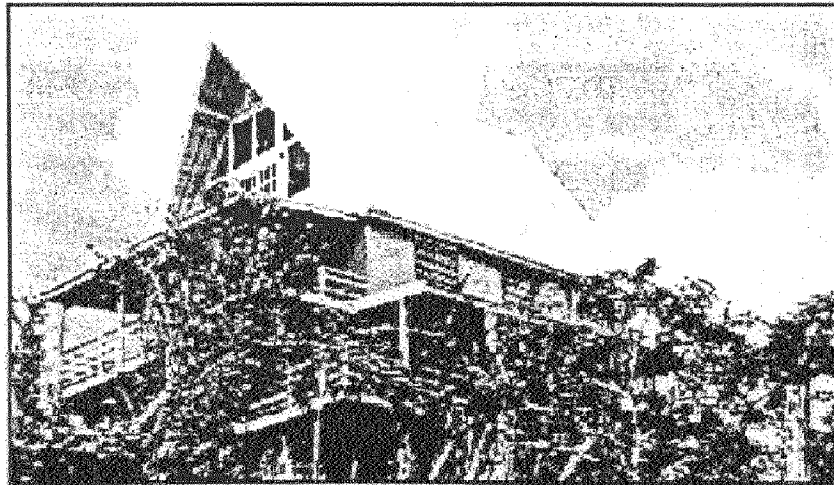

Figure 18. This wooden house stood up to the strong winds generated during Hurricane Georges in Puerto Rico, 1998.

Regardless of the construction technique or construction materials utilized, it is imperative that appropriate connections are furnished to successfully transfer the loads to the ground. Most failures during hurricanes occur as a result of poor connections.

The following is a list of general recommendations, some of which may or may not be directly related to the structural aspects of a building, which could reduce the vulnerability of hospitals against hurricane winds.

- Hurricane clips, screws, and metal flashings should be protected against corrosion whenever they are located within 10 kilometers of the ocean.

- Overhangs and Spanish tiles (clay) as roof covering should be avoided. Separation and launching of roof systems usually begin due to overhang failure. Overhangs are exposed directly to wind actions and generally are not provided with proper connections that resist hurricane winds. Figure 19 shows a house whose overhang did not withstand strong winds and its failure led to a partial detachment of the roof. On the other hand, Spanish tiles are susceptible to becoming wind borne missiles that could cause serious damage to neighboring buildings. In addition, the brittle nature of Spanish tiles makes them vulnerable against strong winds to be removed from the roof even without failure of the roof system itself (Figure 20).
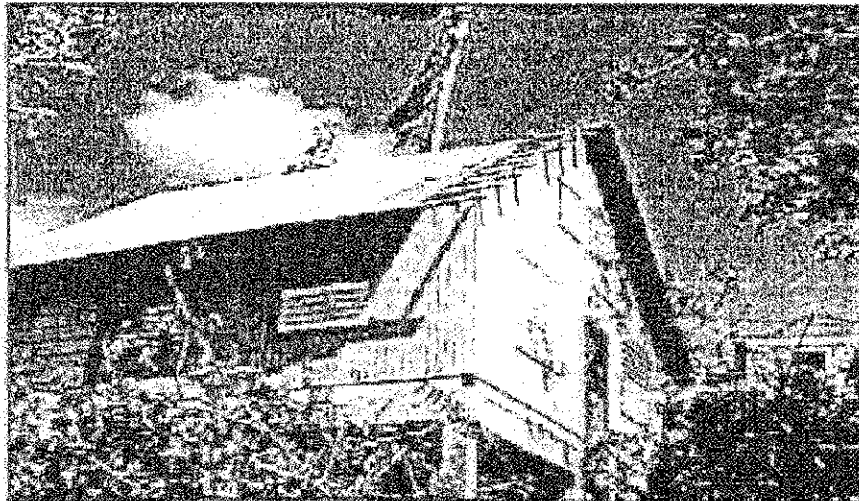

Figure 19. This house was subjected to moderate winds during Hurricane Georges in Puerto Rico (1998). The only damage sustained by the house was in fact the overhangs that failed and led to the separation and launching of the metal sheets, which were not properly fastened.
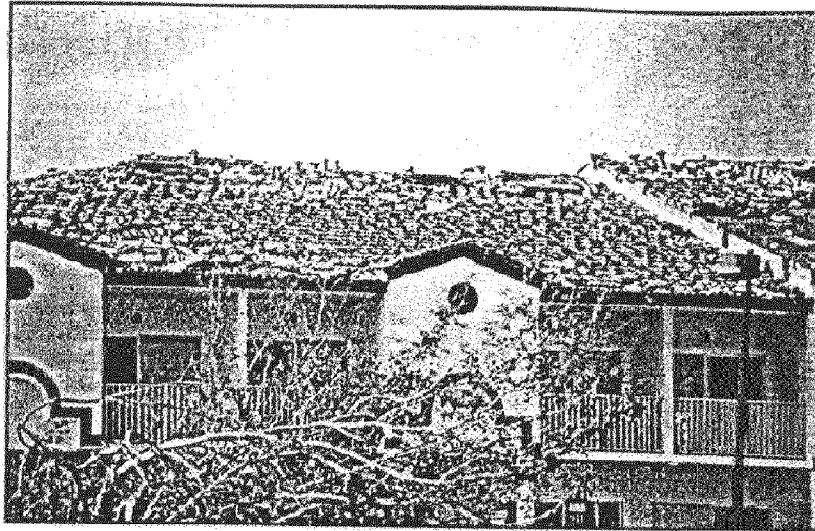
Figure 20. The roof of this house resisted the strong winds of Hurricane Andrew but many of its tiles were detached, turning into dangerous missiles that probably impacted neighboring buildings.

• Hip roofs perform better than gable roofs when subjected to extreme winds (end walls of gable roofs are more vulnerable to wind actions). However, gable roofs are preferred over flat or monoslope roofs whenever the end walls are adequately braced if wooden construction or anchored if masonry construction.

• Roofs can be tied down with steel cables to provide additional resistance against roof detachment. Even though this practice has not been demonstrated through testing, tied down roofs have shown to perform well during hurricanes.

• Construction over hills and ridges should be avoided since wind tends to speed up due to topographic effects. Wind speed acceleration due to sudden changes in topography may increase wind pressures up to 80%.

• Surrounding trees should be kept trimmed to prevent limbs and branches from impacting neighboring hospitals and health centers. Similarly, trees next to hospitals and health centers should be eliminated to avoid situations like the one shown in Figure 21, where a tree fell down on top of a house.
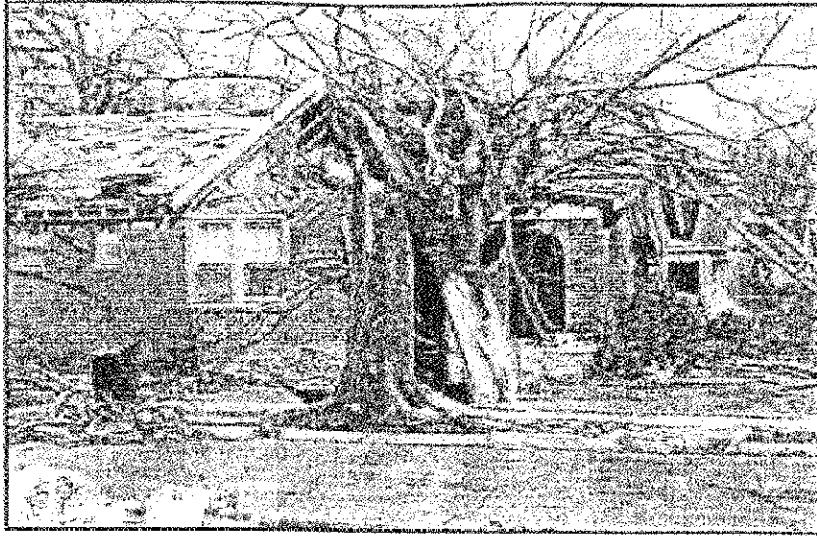
Figure 21. This house resisted the winds produced by a tornado in Little Rock, Arkansas, but a nearby tree caused moderate damage after falling down on it.

• It is important that the surroundings of hospitals be free of loose objects, garbage, and anything that could become a wind borne missile during a hurricane.

• Adjacent buildings should be required to be properly reinforced to protect hospitals from being impacted by missiles that could affect their total or partial functionality immediately after a hurricane (Figures 22 and 23).
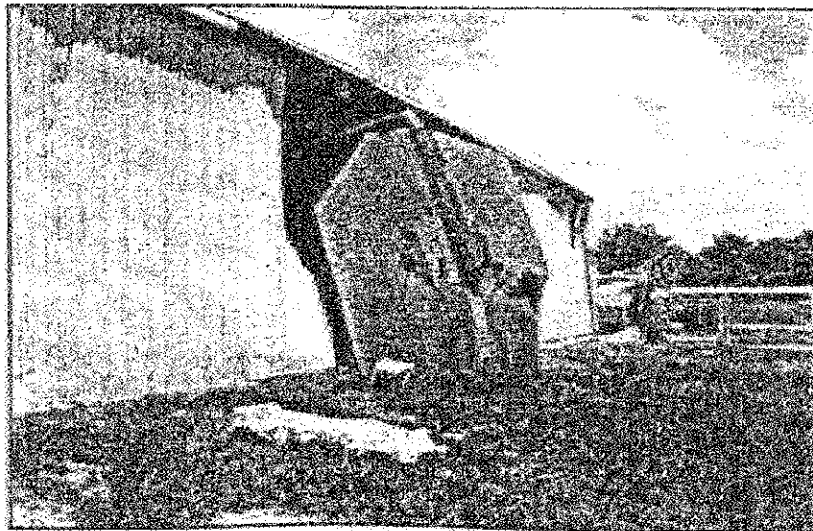

Figure 22. The picture shows a warehouse that was impacted by a roof during a tornado in DeKalb, Texas. The roof belonged to another structure that was located about 100 meters from the warehouse.
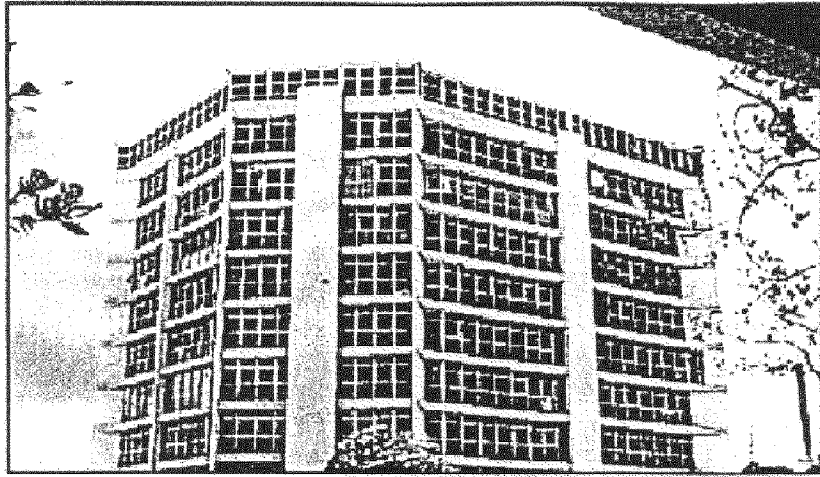
Figure 23. The structural system of this building (located in San Juan, Puerto Rico) resisted the strong winds during Hurricane Georges in 1998. However, many of its windows broke as a result the impact of pebbles from the waterproof system of a roof located across the street. During the storm, water entered the building through the broken windows causing considerable damage.

• Similarly, billboard signs near hospitals (even those not belonging to the hospital) should be designed to resist wind loads according to ASCE 7-98. Otherwise, a hospital may withstand wind loads successfully but a sign flying at over 200 km/h could impact the hospital destroying an exterior wall or part of its roof system. This recommendation is not limited to signs, as other structures such as water storage tanks, radio antennas, and fences could cause similar damage. Figure 24 shows a health center in Isla Culebra, Puerto Rico, that survived the strong winds during Hurricane Georges (1998) but a water storage tank of a house located over 100 meters away impacted its roof. The breached roof allowed water to enter the building causing severe damage and forcing several areas of the hospital to close down.
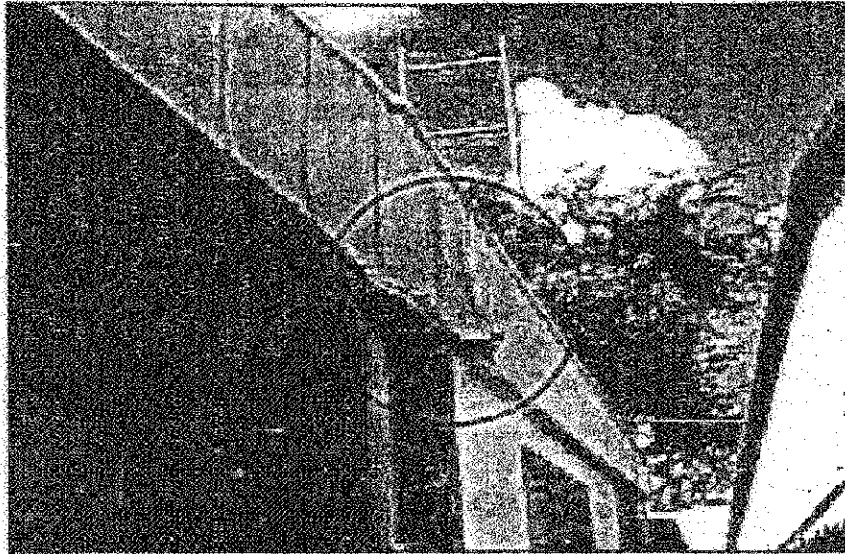
Figure 24. Health center in Isla Culebra affected by the water storage tank of a neighboring house during Hurricane Georges in 1998.

• Energy is usually supplied to hospitals through elevated cables that connect primary posts located in the vicinity of the hospital to secondary posts located just outside the hospital. If wind borne missiles strike these secondary posts during a hurricane, the power supply of the hospital could be interrupted; this would be devastating. Underground connections from the primary posts to the secondary posts could be implemented in order to reduce the probability of power outages in hospitals. In addition, it is recommended that hospitals have permanent access to emergency power generators with enough capability to ensure the operation of the hospital under minimum conditions.

• The geometry of hospitals should be kept as symmetric as possible, avoiding at all moments complex and unusual shapes.

• All mechanical equipment (air conditioners, power generators) located outside the hospital should be properly anchored with bolts and nuts to protect them from becoming flying missiles.

• All existing health centers should be retrofitted to resist hurricane wind loads. Some of the considerations to be taken into account in determining the order of priority of hospitals for retrofitting against hurricanes include: (1) level of care the hospital provides, (2) age of the hospital (this implies its actual condition, which depends upon its maintenance), (3) type of construction, and (4) degree of vulnerability.

• A national technical committee should be formed to develop and advise on mitigation measures against hurricanes for hospitals and health centers. This

committee should include technical personnel involved in health care as well as maintenance departments of the Ministry of Health, government technical personnel and project management agencies responsible for hospitals, and representatives of professional institutions of engineers and architects.

• Personnel working in health centers should be trained on the appropriate measures that need to be taken before, during, and after a hurricane. The objective is to make sure all personnel know where to go, where not to go, what to do, and what not to do before and during a hurricane. This measure may help to prevent the chaos that is usually created because of the anxiety produced by fear, impotence, and lack of knowledge on what to do during an event of this magnitude.

• Designers and contractors in charge of construction of new hospitals and retrofitting of existing ones should have technical knowledge and experience in the design against hurricane winds. Otherwise, they should work under the supervision and advise of an expert in such field.

• Finally, it becomes an imperious issue the enforcement of those regulations established by local building codes through institutions such as associations of engineers and architects, departments issuing building permits, and other government organisms. Damage documentation and investigation conducted after some historical hurricanes (Alicia in Galveston, U.S., 1983; Georges in Puerto Rico, 1998) demonstrated that most severely damaged buildings did not comply with local building codes.