Guidelines for Prevision Against Wind in Hospitals and Health Centers

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 engineenng, 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 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.

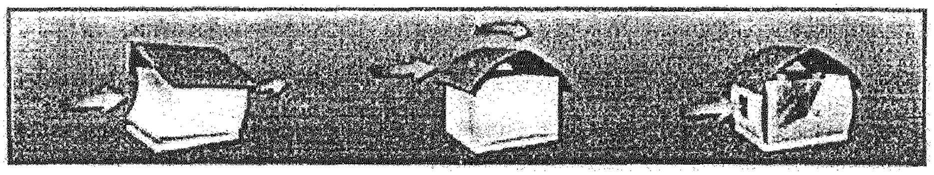

Figure 2. The house to the left shows the effect of pressure on the windward wall and suction on the leeward wall; the center house shows the effect that wind flow over the structure produces on the roof; and the house to the right shows how the openings on a building can create internal pressures that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

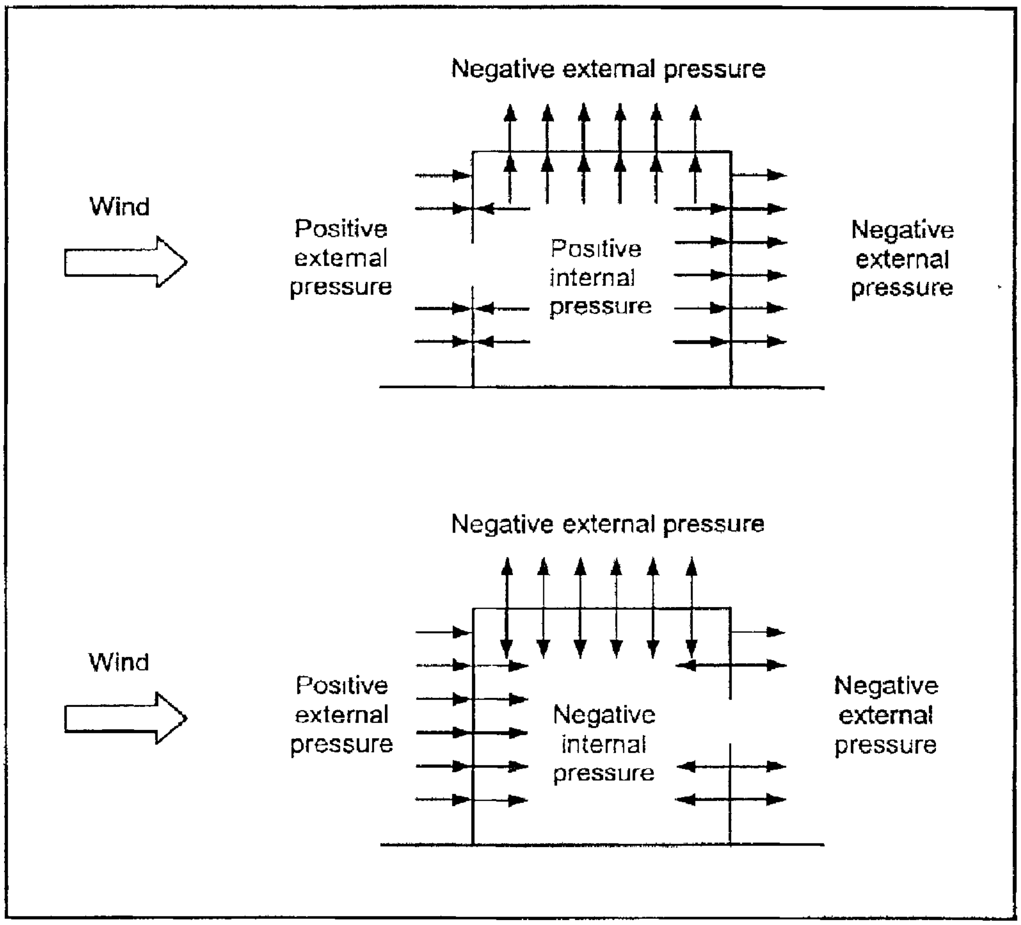

Figure 3. External and internal wind pressures.

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

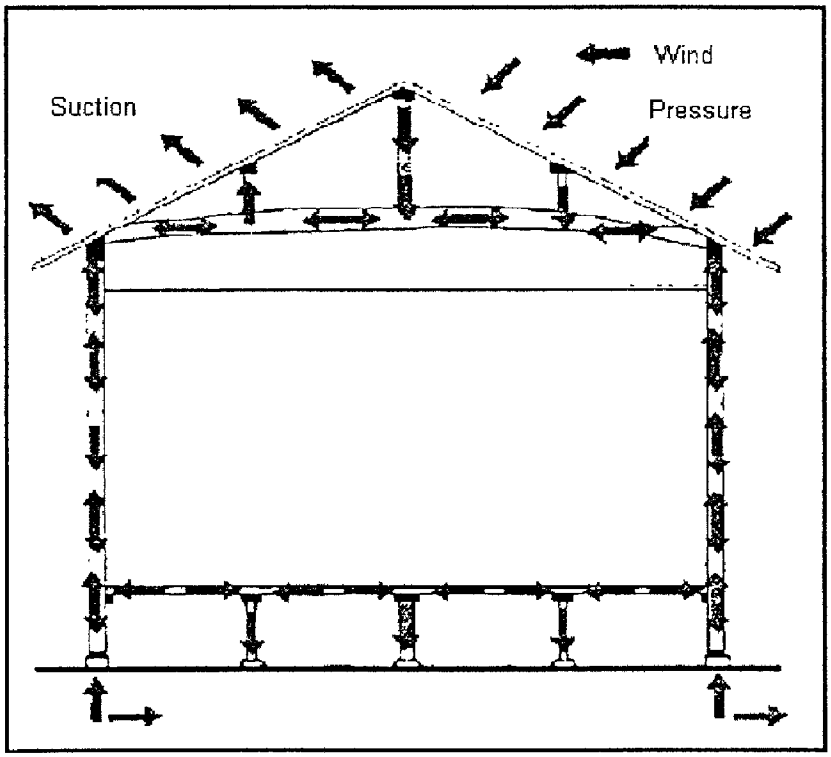

Figure 4. Continuous load path.

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 (½ρV^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:

$$p = q_h[(GC_p) - (GC_{pi})] \qquad \text{buildings with } h \leq 18 \text{ meters}$$

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.

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

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: