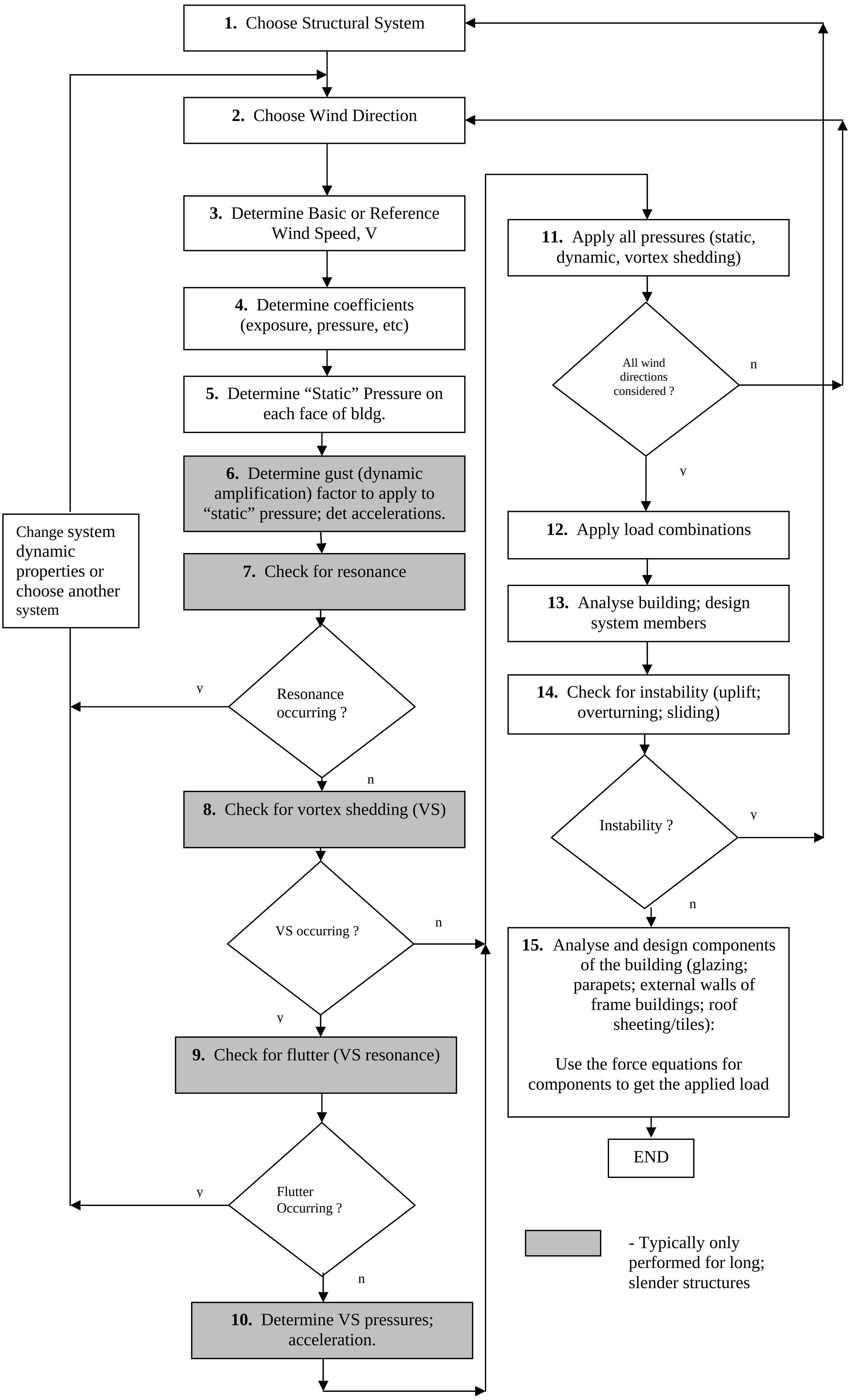
GENERAL PROCESS FLOWCHART FOR HURRICANE-RESISTANT DESIGN OF BUILDINGS



1.0 Wind Load Codes for the Caribbean

In order to design structures for high winds or hurricanes, it is essential that the wind loads be quantified. These loads are determined by reference to wind load codes.

It is useful to categorise the wind load in terms of the phenomena induced by the wind as presented in the above flow chart. That is:-

1. Direct external and internal pressures on the surfaces of the structure, local or averaged
2. Drag forces
3. Inertial forces of dynamic amplification due to gusting of the wind load (mainly for slender structures)
4. Vortex shedding forces (mainly for slender structures)

These forces are determined for the building as a whole (i.e. the structural system), and for exposed components of the building (i.e. cladding, walls, sheeting, bolts/screws/ nails, etc.).

In determining the magnitude of these forces for the Caribbean region, there are at present three main codes available to the structural designer –

1. Code of Practice for Wind Loads for Structural Design by the Barbados Association of Professional Engineers, 1981
2. Structural Design Requirements – Wind Load. Caribbean Uniform Building Code (CUBiC) Part 2 Section 2. 1985.
3. Minimum Design Loads for Buildings and Other Structures - ASCE 7-05, Chapter 6, American Society of Civil Engineers.

Regardless of the code, the primary concept is that the forces depend on the magnitude of the wind speed, the exposure of the structure to the wind, the shape of the structure, and for certain structures, the materials of the structure.

Summary of Caribbean Wind Load Codes Provisions:

CUBiC:

1. The design wind speed is defined relative to a mean velocity over open terrain at an equivalent elevation of 10m, averaged over a period of approximately 10 minutes, and with a recurrence interval of once-in-fifty years. It is important to note that the wind velocity definition can vary among the codes. The sources of these differences are – the measurement height, and the averaging time used (10min, 1hr, 1 min, and 3 seconds). Conversion tables are available.
2. The wind force per unit area is given by the general equation:
   $w = q_{ref}\, C_{exp}\, C_{shp}\, C_{dyn}$

   where w is assumed to act normal to the surface,
   q_{ref} is the reference velocity pressure defined by $0.5\rho V^2$ where ρ is the air density and V is the wind velocity.

   C_{exp} is the exposure factor. It is a dimensionless coefficient that accounts for the variability of the velocity pressure at the site of the structure due to height above ground and terrain characteristics.

   C_{shp} is the aerodynamic shape factor. It is a dimensionless coefficient defined as the ratio of an aerodynamic pressure on the surface of the structure, to a velocity pressure. It is influenced by the geometry and shape of the structure, the exposure, relative wind direction, Reynolds number, and averaging time.

   C_{dyn} is the dynamic response factor. It is a dimensionless factor that accounts for fluctuating pressures due to random gusts in a time frame shorter than the averaging time, and vortex shedding.

3. In this wind load code, there are 2 methods or levels of load analysis referred to as the Simplified Method and the Detailed Method. The Simplified Method provides simplified values of the C factors and is intended for the design of cladding of most normal structures, as well as the main structural system provided that the following criteria are met: the structure is less than 15m in height; the structure is not unusually exposed for any wind direction (i.e. not situated near a hillcrest or headland), and the structure is relatively rigid (i.e. the deflection calculated by the Simplified Method are less than 1/500 of the height of the structure or of the relevant span). If any of these criteria are not met, the Detailed Method must be used.

BAPE:

1. The wind speed is defined relative to a mean velocity over open terrain at an equivalent elevation of 10m, averaged over a period of approximately 3 seconds, and with a recurrence interval of once-in-fifty years.

2. The wind force per unit area is given by the general equation:
   $q = 0.6128V_s^2$

   V_s is the deisgn wind speed and is given by,

   $V_s = VS_1S_2S_3$

   V is the basic wind speed.

   S_1 is the topography factor. It is a dimensionless coefficient that depends on the location of the structure.

   S_2 is a factor that depends on the ground roughness, the building size and the height above ground.

   S_3 is a statistical factor. It is typically unity for most structures except temporary structures, structures where a longer or shorter period of exposure may be expected, or structures where additional safety is required.

   Q determined as above is then multiplied by an appropriate pressure coefficient C_p to give the pressure exerted at any point on the surface of a building. Since the resultant load on an element depends on the difference of pressure between opposing faces, pressure coefficients may be given for external faces, C_{pe} ,and internal faces, C_{pi}. The resultant wind load on an element of the surface acts in a direction normal to that surface and is then,

   $F = (C_{pe} – C_{pi})qA$ where A is the area of the surface.

   The total wind load on the structure may be obtained by vectorial summation of the loads on all surfaces.

3. BAPE offers another and shorter method of finding the total wind load on the building as a whole by using a force coefficient C_f. The total wind load is then,

   $F = C_f\ q\ A_e$ where A_e is the effective frontal area of the structure.

A comparison of the codes indicates that the BAPE code offers a wider range of structural shapes for the determination of the surface pressures, whereas CUBiC offers more tools for accounting for dynamic and vortex shedding effects.

ASCE 7-05:
This is more similar to the BAPE code than the CUBiC code in terms of overall procedure. The Caribbean design practice has increasingly adopted the American codes over the past 15 years or so. However, there is a recent change in the format that is in the process of being considered for current use.

3.0 Hurricane Resistant Design of Non-Residential Structures

According to the International Building Code (IBC 2009 cl. 1604.10) lateral-force resisting systems shall meet seismic detailing requirements and limitations prescribed by the code, even when wind code prescribed load effects are greater than seismic load effects.

3.1 Comparison of Hurricane and Earthquake-Resistant Structural Design[1]

	Wind	Earthquake Effects
(1) Source of loading	External force due to wind pressure	Applied movements from ground vibration
(2) Type and duration of loading	Wind storm of several hours duration; loads fluctuate but predominantly in one direction	Transient cyclic loads of at most a few minutes duration; loads change direction repeatedly
(3) Predictability of loads	Usually good, by extrapolation of records or by analysis of site and wind patterns	Poor; little statistical certainty of magnitude of vibrations or their effects
(4) Influence of local soil conditions on response	Unimportant	Can be important
(5) Main factors affecting building response	External shape and size of building; dynamic properties unimportant except for very slender structures	Response governed by building dynamic properties: fundamental period and mass
(6) Normal design basis for maximum credible event	Elastic response required	Inelastic response permitted, but ductility must be provided; design is for a small fraction of the loads corresponding to elastic response
(7) Design of non-structural elements	Loading confined to external cladding	Entire building contents shaken and must be designed appropriately

3.2 Glazing design

Framing
To be considered firmly supported, the framing members of each individual pane of glass shall be designed so the deflection of the edge of the glass perpendicular to the glass pane shall not exceed 1/175 of the glass edge length or 19.1mm, whichever is less, when subjected to the larger of the positive or negative pressure.

Load
Glass sloped 15deg or less from vertical in windows, curtain and window walls, doors and other exterior applications shall be designed to resist the wind loads for cladding and components.

Design
Glazing firmly supported on all four edges is permitted to be designed by the following provisions.

The design of vertical glazing shall be based on the following equation:

$$F_{gw} \leq F_{ga}$$

Where F_{gw} is the wind load on the glass, and F_{ga} is the maximum allowable load on the glass computed by the following formula.

$$F_{ga} = c_1 F_{ge}$$

For regular (annealed) glass, $c_1 = 1$. Typical values for F_{ge} are (interpolation but not extrapolation is permitted):

[1] From "Design for Multiple Hazards – Conceptual Design of Buildings to Resist Wind and Earthquake Forces" by Tony Gibbs, Consulting Engineers Partnership Ltd.

Pane Thickness	Allowable Pressure
6.4mm	1.5kN/m^2 for 1.77mx1.77m
3/8"	1.6kN/m^2 for 2.28mx2.28m

3.3 Impact resistant design

The following is based on the IBC 2009.

Unless the window glazing in the lower 18.4m of a building is impact-resistant, it shall be considered as an opening and the effect of such opening catered for.

A covering over the window or door shall be considered impact-resistant if compliant with ASTM E 1996 (Standard Specification for Performance of Exterior Windows, Curtain Walls, Doors, and Storm Shutters Impacted by Windborne Debris in Hurricanes). Glazed openings located within 9.1m of grade shall meet the requirements of the Large Missile Test of ASTM E1996. Glazed openings located more than 9.1m above grade shall meet the requirements of the Small Missile Test of ASTM E1996.

An exception to the above is the following timber panel shuttering which is considered to be acceptable:

Wood structural panels with a minimum thickness of 11.1mm and maximum span of 2.4m are permitted for opening protection of one and two-storey buildings. Panels shall be pre-cut to cover the glazed openings with attachment hardware provided. Said hardware shall be designed to resist loads as specified for components and cladding. However, the following attachment is considered adequate for buildings with a mean roof height of 10m or less where (3-second gust) wind speeds do not exceed 57.2 m/s (130 mph).

For a panel span of less than 2.4m, use 2 ½ #6 wood screws at 225mm c/c, or 2 ½ #8 wood screws at 300mm c/c. Such fasteners shall be installed at opposing ends of the wood panel. Where screws are attached to masonry or masonry stucco, they shall be attached using vibration-resistant anchors each having a minimum withdrawal capacity of 2.3kN.