Conceptual Design for Wind

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- The life cycle of a building
- Shape, geometry, configuration
- Non-engineered Buildings
- Air flow around buildings
- Pressure distributions
- Façades (including windows)
- Integrating shutters into the design
- Wind-tunnel testing
- Caution about dynamically-sensitive structures
- Shell and folded plate structures
The Life Cycle of a Building:

1. Design (i.e., conceptual design)
2. Analysis
3. Detailing
4. Construction
5. Maintenance
6. Demolition
Conceptual design involves a series of decisions among which are:

1. the geometry or shape or configuration of the building;
2. the siting of the building;
3. the materials of construction;
4. the structural system.

Shape, Geometry, Configuration
Gabled roof with slopes of 20 to 30 degrees are preferred over flat roof.

hatched area indicates where more frequent fixings are required.
Point Blanche Saint Martin
roof sheeting lost from flat roof
Hipped roof recommended over gable roof

Hatched area indicates where more frequent fixings are required

Sint Maarten overview of roof losses
Sint Maarten overview of roof losses

Most hipped roofs survived Hurricane Irma
St Martin – Success is feasible, not all roof covering was lost
Conceptual Design for Hurricanes
TTIA CPD Seminar

23 July 2018

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Openings. To minimise the reduction in strength caused by openings in walls for doors and windows, openings should not be positioned close to corners, the eaves or the floor.

For each wall, the sum of the lengths of wall between openings (ie dimension ‘a’ should be not less than half the overall length of the wall.

Keep the size of windows as small as possible in the most exposed walls, eg those facing seaward, and position doors in other walls.
non-engineered buildings
Non-engineered Buildings

Structural configuration is the single most important factor in determining the performance of buildings subjected to hurricanes. The following recommendations are proposed and are particularly appropriate for non-engineered construction and for minimum cost construction:

1. Limit height of buildings to one and two storeys.
2. Ensure that lightweight floors and roofs are securely fastened to the walls to improve their performance in hurricanes.
3. The shape of the building should be, as far as possible, symmetrical. This symmetry also applies to the arrangement of partitions and openings. This would lead to a more balanced distribution of forces in the structure.
(4) Provide sufficient distance between openings to avoid slender piers. Keep the openings moderate in width to avoid long-span lintels.

(5) Link the heads of all walls together by providing a continuous collar or ring beam at floor and roof levels.

(6) Lightweight roofs should be not less steep than 20 degrees (generally speaking, the steeper the better up to about 30 degrees) to improve their wind resistance.

(7) To improve their wind resistance lightweight roofs should have a hipped shape (sloping in four directions) rather than a gable shape (sloping in two directions) or a monopitch shape.

(8) Again, to improve their wind resistance, lightweight roofs should have minimum overhangs at the eaves. In fact it would be better to have no overhangs and to introduce a parapet. The need to shade windows and doors from sun and rain may be met by separate canopies.

(9) The incorporation of ridge ventilators would reduce internal pressures and therefore help in keeping on lightweight roofs in a hurricane.
Typical Construction Features that Reduce Wind Damage and Loss

- Roof Deck Attachment
- Secondary Water Resistance
- Roof Shape and Bracing of Gable End
- Protection of Openings
- Roof to Wall Connection
- Protection of Openings
- Roof Covering
- Doors

materials of construction
Typical Framing for Metal Building (with Design Loads for Strut Purlin Shown)
Failure of roof beam due to combined effects of wind uplift and pretension.
air flow around buildings

Turbulent flow of wind on longitudinal and transverse sides of high rise buildings
Turbulent flow on high rise buildings due to upwind obstructions

Wind velocity increase due to large openings at lower floors
Wind flow over gabled roof buildings showing turbulence on leeward roof and walls

Pressure increase due to wind on overhanging roofs
Protection effect of upstream building

A favorable location of adjacent buildings can decrease the hurricane effects reducing the wind loads

Unfavorable location of an adjacent building

A bad location of nearby buildings might induce increase of wind loads
pressure distributions

Pressure coefficients on high rise buildings

Pressure varies with height (Widward)
Pressure keeps constant with height (Leeward)
**Design pressure diagram on gabled roof building**

```
\[ q_{b,GCp} \]
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**Wind direction**

**Notes:**
1. A similar loading with negative internal pressures may be considered; it will have reduced uplift on the roof and will not affect total horizontal shear.
2. The load distribution steps on windward wall are the same as \( q_z \).

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**Design pressure diagram on flat roof building**

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<table>
<thead>
<tr>
<th>Wind direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>106 psf</td>
</tr>
<tr>
<td>17.0 psf</td>
</tr>
<tr>
<td>15.3 psf</td>
</tr>
<tr>
<td>13.0 psf</td>
</tr>
<tr>
<td>10.6 psf</td>
</tr>
<tr>
<td>8.2 psf</td>
</tr>
<tr>
<td>5.6 psf</td>
</tr>
</tbody>
</table>
```

Notes:
1. A similar loading with negative internal pressures may be considered; it will have reduced uplift on the roof and will not affect total horizontal shear.
2. The load distribution steps on windward wall are the same as \( q_z \).
Pressure sketch for wind perpendicular to the ridge on a pitched-roof industrial building:

- Internal Pressure of +3.2 psf
- Internal Pressure of -3.2 psf
- 7.5 psf
- 7.0 psf
- 15 ft
- 200 ft

Pressure sketch for wind parallel to the ridge on a pitched-roof industrial building:

- Internal Pressure (+)
- Net Pressure
- Parallel to Ridge
The smaller the item, the greater the effect.

façades (including windows)
Broken glass made this critical facility unusable for months
Hurricane Ivan, 2004
Government Headquarters, Grenada, Post Hurricane Ivan, 2004
vulnerable glass installed in a critical facility
No lessons learnt

Complete removal of windows, including frames
Norman Manley Law School, UWI
Hurricane Gilbert, Jamaica, 1988
Complete removal of windows
Cornwall Regional Hospital
Hurricane Gilbert, Jamaica, 1988

Photo: Tony Gibbs
Laminated glass consists of two or more lites of glass, bonded together—most commonly—by a plastic inner layer.

Because of its extreme strength, laminated glass can be used for windows in hurricane-prone coastal regions.

While laminated glass may be broken by extreme force, the glass fragments remain bonded to the plastic interlayer.

Laminated Glass Applications: Hurricane Resistance

Increasing hurricane activity – building codes require the use of hurricane-resistant glazing.

Laminated glass used with hurricane-resistant framing meets this demand.

The entire window system—including laminated glass and framing—must pass stringent regional and ASTM International testing, including large missiles (ground level to 30 feet), small missiles (30 feet and up), and cyclical pressure.
Impact-resistant polycarbonate windows
at J N France Hospital
after Hurricane Georges, 1998

Photo: Tony Gibbs

Flying floor board
penetrating
¾-inch plywood shutter
Montserrat Electricity Services
Hurricane Hugo, 1989

Photo: Tony Gibbs
integrating shutters into the design

Permanent window shutter details

- Surface bolts to secure when closed
- Storm shutter in open position
- Shutter panels fixed to frame
Details of roll-up shutter

housing chamber for roll-up shutter

shutter guide

ELEVATION

CROSS SECTION
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wind-tunnel testing
(Caution about dynamically-sensitive structures)

Wind Tunnel Procedure

- Wind tunnel testing is no longer unknown in the design of Caribbean buildings.

- Used for:
  - overall loads on the main wind-force resisting systems;
  - pressures on external cladding;
  - pedestrian conditions adjacent to buildings.
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Hotel – destruction of walls, partitions and much else

Photo: Omar Allahar
St Martin’s Primary School had hyperbolic paraboloid shell roofs. It was undamaged by Hurricane David in 1979. It was demolished before Maria to make room for a larger building.

Photo: Geoffrey MacLean
Roseau Public Market was built in 1971 and was undamaged by Hurricanes David in 1979 and Maria in 2017

Photo: Tony Gibbs

Teachers Training College – folded plate roof

Photo: Anthony Farrell
Northern Education Development Complex

- Cylindrical and groyne-vault shells

- Hyperbolic paraboloid shell roof
Northern Education Development Complex undamaged by Maria

Goodwill RC Parish Church Dominica

Photo: Anthony Farrell
Goodwill RC Parish Church after Maria

Photo: Tony Gibbs