An Holistic Approach

to ensuring that hospitals function

to maximum efficiency

following severe hurricanes in the Caribbean

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The Caribbean
an area of multiple hazards
Hurricanes routinely cause the loss of functionality of referral hospitals in the Caribbean, North and Central America.

This is unacceptable and an avoidable inconvenience for the affected communities.
Princess Margaret Hospital, Jamaica
Hurricane Gilbert (1988)
Central Medical Stores, Grand Turk
(Hurricane Ike, 2008)
Cornwall Regional Hospital, Jamaica (Hurricane Gilbert, 1988)
According to the Economic Commission for Latin America and the Caribbean (ECLAC), between 1981 and 1996:

- 93 hospitals and 538 health centers were damaged as a result of natural hazards.
- Losses amounted to US$3.1 billion.

This could be compared to an extreme situation in which 20 countries in the region had each suffered the loss of 5 major hospitals and 27 health centers.
Hospitals are especially vulnerable to natural hazards

- The occupancy rate is constant, 24 hours a day, year-round.
- It is almost impossible to evacuate a hospital in the event of an emergency.
- The survival of some patients depends on the proper operation of the equipment and the continuity of basic services.
- In emergencies and disasters, medical facilities are essential and must continue to function after the event has taken place.
- Hospitals are highly dependent on public utilities (water, electricity, communications, etc.) which are often interrupted in the event of a disaster.
The Hurricane Hazard
50-Year, 3-sec Wind Speeds for Caribbean
Figure 3.6: Probability of extreme wind speeds in the Caribbean and Amsterdam. Comparison between various sites.

- Miami
- Windward
- Lineward
- AMIS

Wind Load Factor vs Return Period (Years)

- Non-Hurricane
- Hurricane

Mean return period in years

Return Period (Years)

- 1
- 10
- 100
- 1000
- 10000

WIND CODE
FACTOR FOR BUILDING LIFE

- hurricane intensity levels

Date of last building assessment years
- 04
- 05
- 06
- 07
- 08
- 09
- 10
- 11
- 12
- 13
- 14
- 15
- 16
- 17
- 18
- 19
- 20
- 21
- 22
Load Factor – Contour plots of \( \left( \frac{V_{700}}{V_{50}} \right)^2 \)
Importance Factor for ASCE category III and IV structures defined by $I=(V_{1700}/V_{700})^2$
1700-Year 3-sec Wind Speeds for Caribbean
700 year Return Period Wind Speeds for Puerto Rico
1700 year Return Period Wind Speeds for Puerto Rico
- ASCE 7 Basic Wind Speed, \( V \) – 3-sec, 33 ft height, Exposure C, 50 years

- For same level of safety in the Caribbean a pseudo-50-year wind speed \( = \frac{V_{700}}{\sqrt{1.6}} \) must be used instead of the real \( V_{50} \).

- Alternatively the real \( V_{50} \) could be used with an upward adjustments to the Load Factors and Importance Factors.

- Alternatively, the Basic Wind Speed could be taken as \( V_{700} \) for Category II buildings and \( V_{1700} \) for Categories III and IV buildings, with the Load Factor and Importance Factor both \( = 1 \). This last approach will be simpler in a regional context.
Load Combinations
(factored loads using strength design)

1: \( 1.4(D + F) \)
2: \( 1.2(D + F + T) + 1.6(L + H) + 0.5(Lr \text{ or } R) \)
3: \( 1.2D + 1.6(Lr \text{ or } R) + (L \text{ or } 0.8W) \)
3a: \( 1.2D + 1.6(Lr \text{ or } R) + (L \text{ or } 0.8W_{700}/1.6) \)
4: \( 1.2D + 1.6W + L + 0.5(Lr \text{ or } R) \)
4a: \( 1.2D + 1.0W_{700} + L + 0.5(Lr \text{ or } R) \)
5: \( 1.2D + 1.0E + L \)
6: \( 0.9D + 1.6W + 1.6H \)
6a: \( 0.9D + 1.0W_{700} + 1.6H \)
7: \( 0.9D + 1.0E + 1.6H \)
Topographic Effects
Sketch showing effects of topography on wind velocity on a hilly island
Puerto Rico – Hurricane Georges, 1998

Risk Management Solutions
Climate Change
Caribbean Landfalling TCs

More landfalls during warm phase of AMO

AMO = Atlantic multi-decadal oscillations
Projections for the average number of NATL tropical cyclones for 2025
(1°F warming)

# of Tropical Cyclones:
• Avg for last 50 yrs: 10
• Avg last decade: 14
• Avg ca. 2025: 15-20
category 4+5 3-4

The combination of greenhouse warming and natural variability will produce unprecedented tropical cyclone activity in the coming decades

NAtl = North Atlantic  Georgia Tech
Percentage Increase in Basic Wind Speed in Lucia vs Percentage Increase in Annual Rates of Category 4 and 5 Hurricanes

- Percentage Increase in Basic Wind Speed
- Percentage Increase in Annual Rates of Category 4 and 5 Hurricanes

Graph showing:
- Increase in Basic Wind Speed on the y-axis
- Increase in Annual Frequency of Category 4 and 5 Hurricanes on the x-axis

- Black line: Category II Buildings
- Green line: Category III and IV Buildings
Holistic Approach – the programmes include:

- education of engineers and architects;
- post graduation training of engineers and architects;
- development of building standards;
- development of code “overlay” documents dealing specifically with referral hospitals;
- implementation of independent reviews of designs and of quality assurance during construction;
- attention to the non structural components;
- vulnerability assessments of existing hospitals;
- retrofitting actions for vulnerable, existing hospitals;
- maintenance programmes.
Education of Engineers and Architects
Wind patterns around buildings

Outward pressure on four of the five surfaces
Inward pressure on the windward face only
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 coefficients on high rise buildings

Pressure keeps constant with height (Leeward)

Pressure varies with height (Widward)
Dynamic Response

- Along-wind vibration (buffeting)

- Cross-wind vibration (vortex shedding)
  - Most common with cylindrical structures.

Wind flowing around bluff bodies
Vortices shed behind the structure
Vortex Shedding

- Usually present with bluff-shaped, cylindrical bodies

almost always present with bluff-shaped cylindrical bodies
development of code “overlay” documents dealing specifically with referral hospitals
Safe Hospitals Initiative

Definition:

“ A health facility whose services remain accessible and functioning at maximum capacity and in the same infrastructure, during and immediately following the impact of a natural hazard.”
The Life Cycle of a Building:

(1) Design (*ie* 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.
attention to the non-structural components
PAHO/WHO - Disaster Mitigation in Health Facilities: Structural Issues
vulnerability assessments of existing hospitals
They assess quickly and simply the structural safety conditions of the building. The structure is rated, among other characteristics, according to the following:

- The age of the building
- The state of conservation
- The characteristics of the materials used
- The number of stories
- The architectural plan
- Estimation of base shear strength
The goal is to determine the levels of resistance, flexibility and ductility demands of the structure by means of an analysis similar to that used in new buildings, incorporating nonstructural elements.
Assessment methods

• Previous experience
• Analysis - mathematical simulation
• Laboratory tests
• Expert opinions
## Nonstructural components to consider when assessing vulnerability

<table>
<thead>
<tr>
<th>ARCHITECTURAL</th>
<th>EQUIPMENT</th>
<th>BASIC INSTALLATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Facades</td>
<td>• Medical equipment</td>
<td>• Industrial gas piping</td>
</tr>
<tr>
<td>• Roofs or decks</td>
<td>• Laboratory equipment</td>
<td>• Steam</td>
</tr>
<tr>
<td>• Parapets</td>
<td>• Industrial equipment</td>
<td>• Air-conditioning systems</td>
</tr>
<tr>
<td>• Chimneys</td>
<td>• Supplies</td>
<td>• Heating</td>
</tr>
<tr>
<td>• External plaster</td>
<td></td>
<td>• Ventilation</td>
</tr>
<tr>
<td>• Glass windows</td>
<td></td>
<td>• Electrical distribution</td>
</tr>
<tr>
<td>• Attachments (signs, antennae,etc)</td>
<td></td>
<td>• Back-up power</td>
</tr>
<tr>
<td>• Ornaments</td>
<td></td>
<td>• Communications</td>
</tr>
<tr>
<td>• Canopies</td>
<td></td>
<td>• Drinking water</td>
</tr>
<tr>
<td>• Lighting system</td>
<td></td>
<td>• Industrial water</td>
</tr>
<tr>
<td>• Railings</td>
<td></td>
<td>• Sewerage</td>
</tr>
<tr>
<td>• Doors and exit routes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Expansion joints</td>
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Waterproof membrane removed

Photo: Tony Gibbs
Gabled roof with slopes of 20 to 30 degrees are second best against hurricanes.
Hipped roof recommended over flat roof

Hatched area indicates where more frequent fixings are required

PLAN

ISOMETRIC

Hipped roof
Connection details between metal sheet roof and purlins

Metal sheet fixings and purlin-to-rafter connection

- metal sheeting
- purlin
- galvanized hurricane strap fixed to rafter and purlin
- rafter
- purlin
- self-tapping screw
- ridge connection
- valley connection
- spacer block
Accessories for fixing all profiles
Cyclone Washer: Example of one type specified by manufacturers.

Also specified:
- Spacing of fixings
- Increased fixing at roof edges and changes in slope
- Special requirements (e.g., holes through sheet to be predrilled, screws not to be overtightened, etc.)

Example of fixing for sheet metal product
(Exact requirements given by manufacturer)
Loss of Spanish tiles – Miami, Hurricane Andrew, 1992
EAVE STORM CLIP FASTENED TO SOLID DECK

- Eave storm clip fastened to solid deck
- Metal or rubber closure

FIELD STORM CLIP FASTENED TO SOLID DECK

- Field storm clip fastened to solid deck

FIELD STORM CLIP FASTENED TO BATTEN

- Field storm clip fastened to batten
Polycarbonate, impact-resistant windows

Photo: Tony Gibbs
housing chamber for roll-up shutter

Details of roll-up shutter
Norman Manley Law School, Hurricane Gilbert, 1988

Photo: Tony Gibbs
Interaction between structural and non-structural elements

- **Component A**
  - Story where the partition walls do not interact with the structure
  - Story with interactions between structural and nonstructural elements that modify the behavior of the structure

**A-A Cross Section**

**Detail of A**
Considerations regarding partitions, façades, and windows

Separation between Structural and Architectural Component

Material (Strength, Stiffness, Deformation Capacity)

Placement and Condition

Structural Component

Architectural Component

Fire-Resistant Seal

Transversal Stability, Longitudinal Deformation Capacity

Anchoring

Structural Component

PAHO/WHO - Disaster Mitigation in Health Facilities: Nonstructural Issues
### Criteria for equipment classification

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<tr>
<th>Category</th>
<th>Description</th>
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<tbody>
<tr>
<td><strong>Indispensable</strong></td>
<td>Equipment that can not easily be replaced and is essential for the provision of health services</td>
</tr>
<tr>
<td><strong>Essential</strong></td>
<td>Similar to indispensable equipment, except that it can be replaced promptly</td>
</tr>
<tr>
<td><strong>Hazardous</strong></td>
<td>Equipment that can injure people and damage objects</td>
</tr>
<tr>
<td><strong>Chaotic</strong></td>
<td>Equipment whose failure may cause disruption to its environs</td>
</tr>
<tr>
<td><strong>Functional</strong></td>
<td>Equipment that is not used for emergency health care</td>
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</tbody>
</table>
Maximum Wave Heights (50-year return)
Maximum Storm Surge (50-year return)
Hurricane Wilma, Havana, 2005
Grand Cayman Hospital – Hurricane Ike, 2004

Photo: Tony Gibbs
Intensity-Duration-Frequency Curves
SEVERE WINDSTORMS
CASE HISTORIES

CAUSES OF DAMAGE

- WIND PENETRATING BUILDING ENVELOPE
- UPLIFT OF ROOF SYSTEM
- FLYING DEBRIS
- STORM SURGE, FLOODING, AND LANDSLIDES
- IRREGULARITIES IN ELEVATION AND PLAN
- POOR WORKMANSHIP
- IGNORING NON-STRUCTURAL ELEMENTS
implementation of independent reviews of designs and of quality assurance during construction
Hurricane Luis in Sint Maarten and Saint Martin

**Dutch side** (Netherlands Antilles Meteorological Service):
Highest gust 99 knots or 51 ms$^{-1}$

**French side**:
No anemometer measurements available
Dutch side:
Catastrophic damage
- 100% GDP direct
- 100% GDP indirect

French side:
Not much damage
UWI – Hurricane Gilbert, Jamaica, 1988

Photo: Tony Gibbs
UWI – Hurricane Gilbert, Jamaica, 1988

Photo: Tony Gibbs
Atlantic LNG Train-4 Jetty-2
ELEMENAS OF RISK

HAZARDS

EXPOSURE

VULNERABILITY

LOCATION
THE CHAIN OF SUCCESS

- selecting consultants
- terms of reference for design consultants
- the role of the design team leader
- agreeing the performance expectations of the facility
- agreeing the design criteria for wind, torrential rain and storm surge
- focusing on the non-structural components
- independent reviews of designs
- vulnerability audits of existing facilities
- setting priorities for retrofitting and implementation of recommended actions
- maintenance of existing facilities
Numbers of hospitals were in ruins, including the important Real Hospital de San Lázaro. At the moment of greatest medical need, La Habana de San Cristóbal found itself with limited capacity to care for the thousands of injured habaneros. ‘All my work has been lost...’ despaired Alfredo Saurulle, director of the Real Hospital de San Lázaro. ‘The principal entrance has collapsed......Various wards and the new infirmary building have suffered much damage; all the roofs are ruined.’ – from *Diario de la Marina* (San Francisco de Borja Hurricane of 10-11 October 1846.)

*Plus ça change, plus c’est la même chose.*