Architectural Resilience for Disasters

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By
Janice Olshesky, AIA, LEED AP
National AIA Disaster Assistance Committee
Olshesky Design Group, LLC
Alexandria, VA
Hazard Mitigation Strategy

1. Understand Your Risks

2. Community Vulnerability Assessments
   1. Prepare a Hazard Analysis
   2. Identify Assets
   3. Vulnerability Assessment
Hazard Mitigation Strategy

3. Develop a Mitigation Strategy

A. Hazard Mitigation Goals

B. Identification and Analysis of Mitigation Measures

1. Land Use Regulations
   a. Coastal Setbacks, based on erosion & inundation zones
   b. Flood Regulations, based on Flood Insurance Rate Map
   c. Zoning Code
   d. Hazard Assessment as Part of Land Use Decisions
Hazard Mitigation Strategy

2. Building Standards
   a. International Building Code
   b. Vulnerability Audits and Retrofits
   c. Standards or Guidelines
   d. Training

3. Community Plans
   a. Isolated Communities
   b. Special Interest Groups

4. Public Awareness

5. Incentives – Tax Incentives, loans, grants
Major Natural Disaster

2010 Haiti Earthquake
catastrophic magnitude 7.0Mw
12 January 2010
Haiti Tectonics, Major Faults

Map of the North American - Caribbean tectonic plate boundary. Colors denote depth below sea level and elevation on land. Bold numbers are the years of moderately large (larger than about M7) historical earthquakes written next to their approximate location. Asterisk - Location of the January 12, 2010 earthquake. Barbed lines - boundary where one plate or block plunges under the other one. Heavy lines with half arrows - faults along which two blocks pass each other laterally. [Click on image for larger version.]
Figure 1: Historical Seismicity in Hispaniola prior to 1960. Last major earthquake near Port-au-Prince was in 1770.

Source: USGS
Haiti Damage Summary

- 20,000 Commercial Buildings – collapsed or damaged beyond repair
- 225,000 Residences– collapsed or damaged beyond repair

- Estimated 75% of city’s combined commercial and residential structures will need to be torn down (Gerard-Emile Brun, President Rene Preval’s Commission to evaluate damage and recommend ways to solve housing crisis, WSJ, 1/23/10)

- Government Buildings
  - National Presidential Palace
  - National Assembly
  - Supreme Court
  - Prison Civil de Port-au Prince
  - Ministry of Finance, Education, Communication and Culture

- Port-au-Prince Cathedral
Design and construction practices

Haiti

- Critical facilities/Engineered buildings –
  - Type –
    - Reinforced concrete (RC),
    - RC with infill walls,
    - Masonry block,
  - Design
    - No seismic design,
    - Substandard material

- Single family dwellings –
  - Type
    - Unreinforced masonry
    - Adobe
    - Concrete block or RC
    - No seismic design
    - Poor materials
    - High concentration

- Infrastructure – no seismic design
  - Lifelines
  - Transportation systems
Lifeline Damage, Haiti

- Downed Power Lines
- Road Blockage
- Failed Bridges
- Failed Water/Sewer System
- Port Facilities, etc.

Source: Anne Kiremidjian, PhD
OAS study on existing buildings, Haiti, completed 12/09

- **Study detailed many flaws** and concluded far less serious disaster would destroy many of Haiti’s buildings:
  - Weak or missing reinforcement
  - Structures on steep slopes with unstable foundations
  - Inadequate or nonexistant inspections
  - Poor designs, materials and techniques

OAS study not yet released
Miami Herald, 01/24/10
Downtown Port-au-Prince Ravaged by Quake, Haiti
Salesian Mission School collapsed by Quake in Slum of Cite Soleil, Haiti
Hotel Montana, Haiti
4-star hotel

originally built in 1946
Expanded to include shops, a swimming pool and conference facility.
Hotel Christopher, Haiti – United Nation Stabilization Mission Headquarters
3-star hotel

UN Employees:
83 deaths, 23 missing

Sydney Morning Herald, Jan 28, 2010
The Cathedral of Our Lady of the Assumption, Haiti

Built between 1884 and 1914, and was dedicated on December 13, 1928

Before

After
Market / Commercial, Haiti
Existing Conditions Before Earthquake

Wood
Market near Marche de Fer
Port-au-Prince, Haiti

Concrete
Iron Market
Port-au-Prince, Haiti

Masonry & Concrete
Store: Dedette
Port-au-Prince, Haiti
Residential, Haiti
Existing Conditions Before Earthquake

Masonry
Residential Neighborhood
Port-au-Prince, Haiti

Wood
Cite Militaire
Port-au-Prince, Haiti

Miscellaneous Materials:
Corrugated Steel,
Plywood & Plastic

Slum of Le Saline
Port-au-Prince, Haiti
Buildings that Survived

Reinforced Concrete Construction, Haiti

*Built to International Building Code Requirements*

Digicel 12-story Tower (tallest bldg in Port Au Prince)
Port-au-Prince, Haiti

US Embassy
Port-au-Prince, Haiti

Images Source: Google/Geoeye

Buildings that Survived, Residential Sandbag Construction, Haiti

Earthbag Sun House, Les Cayes, Haiti
Approximately 90 miles from Port-Au-Prince, the Sun House survived undamaged during Haiti’s 7.0 earthquake. Neighboring buildings were destroyed.
Cal-Earth earthbag construction meets requirements for California Earthquake Building Codes
Optional Designs for future:
Earthquake and Hurricane Resistant Systems

Bamboo- Residential

Bamboo system
Can be engineered to meet earthquake and hurricane conditions.

Bamboo House, India

© 2009 Bamboo Technologies
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Bamboo Building Methods

Resilient Bamboo Housing, Concept Sketch
Sri Lanka

Bamboo House - India

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Steel Frame - Residential & Commercial

Steel Frame on Concrete Slab

System can be engineered to comply with CA Seismic Building Code and Miami Dade Hurricane Code

Completed Steel Frame House, 400 sf

4-story steel frame, Mauritius
Structural Concrete Insulated Panel, SCIP
Residential & Commercial

Can be engineered to meet seismic and hurricane requirements.

Photos taken after Hurricane Andrew in Homestead, FL. See roof picture below.

© 2005 Janice Olshesky
Ministry of Housing, Colombo, Sri Lanka. Example Housing

Images with permission from Advanced Structural Panel Industries, LLC
Structural Concrete Insulated Panel, SCIP

Before Hurricane Ike

Image courtesy Google Maps

Crystal Beach House, Bolivar Island, Texas
Post Hurricane Ike


Post Hurricane Ike
Building Configuration

Audubon Houses, Bolivar Penninsula, Texas
Building Configuration

School, Bolivar Penninsula, Texas
Blue Water Hotel: Open Piazza at Ground level allows the wave energy to pass through the structure and minimize damage
Reinforced Concrete
Blue Water Hotel, Wadduwa, Sri Lanka

View from the Sea, Indian Ocean
Blue Water Hotel, Wadduwa, Sri Lanka
elevated structure on columns

View to Indian Ocean beyond
Building Configuration Recommendations - Flood
Lighthouse Hotel, Galle, Sri Lanka

Built along oceanfront on rock outcropping, buttressed base
Building Configuration- Flood Structure with many openings
Lighthouse Hotel, Bath House

Damage was minor to this structure as water could move through it.
Design and Construction Guidelines

Reinforced concrete and bamboo roof: Civic Pavilion - Sri Lanka

Elevation

Section – Civic Pavilion with Marketplace at Ground level, and first floor provides extended shelter during floods. Allows wave energy to pass through the structure.

Elevated Structure, Colombo, Sri Lanka

Historic Structure design, Colombo, Sri Lanka
Framing Construction and Connections

- Recommended connections from foundation to roof

Source: FEMA
Site and Ecosystem
Yala Safari Hotel

Before

After

Photo Source: USGS

© 2005 Janice Olshesky
Yala Safari Hotel

Before the Hotel was constructed, the natural sand dunes were removed for the guest’s view of the Ocean.

The Yala Safari Hotel was completely destroyed by the Tsunami.
Site and Ecosystem
Yala Safari Cabins

Ecosystem was undisturbed during construction

This is a view to the Ocean from the Dining Hall.

Ecosystem was undisturbed at Yala Safari Cabins. The sand dunes and mangrove trees were left intact. The Manager told us the water in the lagoon rose up but not too high. He explained the cabins sustained only minor damage, roof shingles had to be replaced.
Yala Safari Cabins

View from Dining Hall looking away from the Ocean from the same vantage point as the previous slide.
Existing Haiti Building Codes - OAS report

• There is no national Building Code in Haiti.

• When technical standards are used, choice is by engineer responsible for design of projects. Determined by the education background of the engineers.

• Most common norms are:
  • ASCE 7-02
  • French Norms
  • Canadian Norms

  (Source: Organization of American States)

• Lack of enforcement
Recommendations
Multi-Hazard Approach

• Address the multi-hazard problem
  – Earthquakes
  – Hurricanes
  – Mud/landslides
• Develop earthquake hazard maps (Kiremidijan PhD)
  – Ground shaking
  – Liquefaction potential
  – Landslide potential
• Develop hurricane hazard maps
• Develop maps for other hazards
• Design a country-wide land use map that takes into consideration these hazards
Recommendations

Haiti Design/Construction Requirements

• Develop/adopt Building Codes and other infrastructure codes
  • Work with Caribbean Building Code (CUBIC), which does exist.
    – Seismic
    – Hurricane
    – Everyday loads

• Adopt FEMA enhancements

• Consider geological hazards – landslides, liquefaction, coastal erosion (Anne Kiremidjian, PhD)

• Consider environmental impact

• Include ideas of sustainability

• Use indigenous materials whenever possible/prudent and cost effective
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  Olshesky Design Group, LLC
  Alexandria, VA 22314
  www.odesigngroup.com
  703-548-0179 phone