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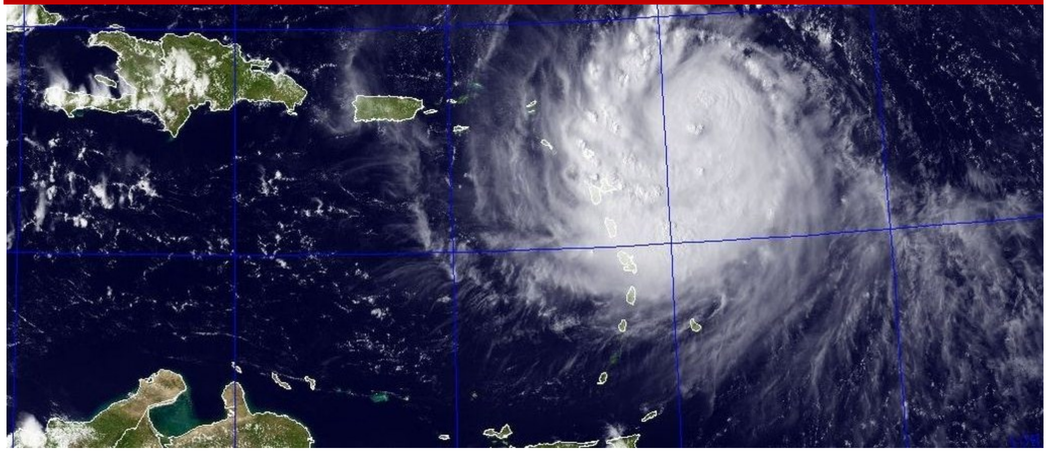
Inside this issue:

International Association for Wind Engineering

SPECIAL ISSUE: Caribbean Wind Research and Topics



Vulnerability of Caribbean Residential Infrastructure to Tropical Cyclones

A Case Study of the Island of Trinidad

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Introduction

In local “island” parlance, the saying goes that “God must be a Trini” to explain the charmed existence of the Trinidad population being spared the wrath of hurricanes and earthquakes. While more than 27 major hurricanes have made dramatic impact on the population of 40 million peoples in the Caribbean over the past 50 years, (Prevatt et al., 2010), the peoples of Trinidad have been spared the brunt of the suffering - experiencing only three landfalling hurricanes over the past 150 years.

Trinidad has, however, experienced considerable damage and losses from inland flooding caused by heavy downpours associated hurricane rain bands (i.e. Tropical Storm Fran, 1990, Hurricane Isaac 2012). In these events, flooding occurs in heavily urbanized areas in the northeast of the island, as well as in the vast Caroni River basis located south and east of the capital city, Port of Spain. In many instances such flooding has severed the transportation links between the north and south of the island for days because major highways had flooded and were impassable. Thus, it is not surprising that wind hazard issues are not of strong concern to the Trinidadian and this is reflected in poor choices that are made in structural engineering of residential buildings.

Minor (1983) commented on how construction traditions are shaped by the recent (in living memory) of major natural hazards. Immediately after an event, building practices change to adopt those structural systems that performed well and to eliminate others found lacking. They observed that in Caribbean islands with recent hurricane landfall (less than 10 years) residential construction practices are more resilient to wind loading than their counterparts in less frequently impacted islands. Minor's observations can be seen in the 2004 Hurricane Ivan, comparing performance of residential structures in Grenada and in the Cayman Islands. In the former case over 90% of residential structures were destroyed, compared with less than 15% in the Cayman Islands (Prevatt et al., 2010). Prior to 2004, the Cayman Islands had experienced 16 hurricanes and versus 4 hurricanes for Grenada in the previous 100 years (Caribbean Hurricane Network, 2011).

The vulnerability of Caribbean islands to hurricanes is quite variable, due in part by the large variation in annual likelihood of tropical cyclone activity, from less than 1% in the southern island of Trinidad to greater than a one-in-five chance (20%) in the northern Bahamas islands (Pielke et al., 2003). The vulnerability of residential housing in this region is exemplified in Montserrat where Hurricane Hugo (1989) destroyed 90% of the island's homes, leaving an estimated 12,000 residents temporarily homeless (Prevatt et al., 2010).

The other variable however, is the quality of construction, exemplified by building codes in each island, level of enforcement and the level of application of mitigation techniques incorporated into the structures. While the Cayman Islands adopted the SBBCI building code, the residential structures in Grenada relied upon a prescriptive building code. Further, a large proportion of the building stock would have been "squatter" housing that is essentially outside the domain of any organized oversight.

Post-damage surveys in the Caribbean show variability of performance. One obvious thing is the critical impact that such losses have on the economy of the islands. Small Island vulnerability research (Briguglio, 1995 and Kelman, 2012) has shown that a hurricane's impact on small-footprint islands is deeper and more long-lasting that as occurs in larger or continental-sized countries. For example, Hurricane Ivan (2004) caused $18.8 billion in damage to the Florida and Gulf Coast states (NOAA, 2011) (approximately 0.06% of GDP). The same hurricane caused $1.1 billion in damage to Grenada and $3.5 billion in the Cayman Islands (World Meteorological Organization, 2007) – which was 133% and 107% of GDP, respectively. The concern for the island of Trinidad is given its limited historical experience with landfalling strong hurricanes, building practices have not evolved to include known damage mitigation techniques, structures (particularly houses) have not been systematically maintained and at least two generations of the population living in Trinidad have grown up and constructed buildings with little knowledge and limited consideration for potential wind hazards.

This makes Trinidad an interesting case study on the development and vulnerability of residential infrastructure in a region where the threat of tropical cyclones exists, but is largely ignored in residential design and construction. This article briefly details the history of tropical cyclones in Trinidad and the residential construction practices employed in the region with commentary on the vulnerability of current residential construction methodologies. By highlighting these shortcomings it is hoped to combat the 'wind hazard amnesia' that exists and serve as a wake-up call for more responsive engineering design practices.

Trinidad's Tropical Cyclone History

From 1851 to 2010, a total of 11 tropical cyclones have passed within 69 miles of Trinidad. Storm intensities ranged from tropical storm (7 of 11) up to Saffir-Simpson Category 3 (Hurricane Flora 1963) (Caribbean Hurricane Network, 2011). As shown in Fig. 1, the majority of the cyclones tracked across the northern side of the island near the largest city in Trinidad, Port of Spain.

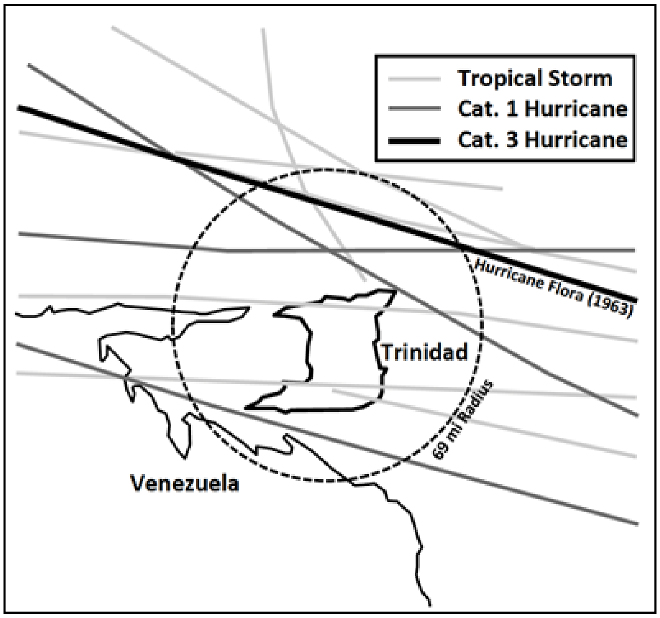


Figure 1. Tropical cyclone activity near Trinidad (1851 – 2010)
Source: stormcarib.com/climatology/TTPP_all_isl.htm

Scant data exists on the performance of Trinidad's residential infrastructure in these cyclones. The most relevant observation comes from Prevatt (1994) on Tropical Storm Fran (1990), which had sustained winds of 13 m/s and gusts up to 19 m/s. Poor construction of the roof-to-wall connection was most common failure mode of damaged home.

Trinidad's Design Wind Speeds

In 2008, the CARICOM group of nations, including Trinidad and Tobago, adopted wind provisions for engineered structural design that utilize the ASCE 7-05 Ch. 6 methodology (Gibbs 2008). Prior to that the Caribbean Uniform Building code (CUBiC) was the primary wind load design guide. Recently, Caribbean design wind speed maps were developed by Vickery and Wadhera (2008). Owing to the historically increased frequency and intensity of tropical cyclones in northern Trinidad, design wind speed (700 year return period) for northern Trinidad is 61 m/s (136 mph), while southern Trinidad is 37 m/s (82 mph). For comparison, the highest Caribbean design wind speeds are found in the Grand Cayman with a design speed (700 year return period) of 84 m/s (187 mph).

The primary source of vulnerability of the Trinidad housing is a combination of inadequate training of construction workers, minimal construction inspection, and lack of enforcement of minimum building code requirements (Prevatt et al., 2010). It is likely that the newly adopted building code will not affect its residential construction because the provisions do not address the root sources of vulnerable housing in new construction, nor does it tackle the vulnerability of the existing residential building stock (Prevatt et al., 2010).

Residential Construction Practices

Economics plays a leading role in the construction practices used for a residence. If engineered, residential buildings are designed to resist both seismic and wind hazards. The vulnerability of residential structures in the Caribbean can be viewed in three distinct categories (Prevatt et al., 2010):

1. The informal construction located on unstable hillsides

Figure 2. (a) Typical residential neighborhood in Port of Spain, Trinidad. (b) Single- and (c) two-story modern concrete masonry block homes with large eaves extending outwards on all sides. (d) A 1.2 m (4 ft) wide cantilever roof overhang at the ridge of a double-lean-to roof, northwest Trinidad, (Photos by David O. Prevatt)

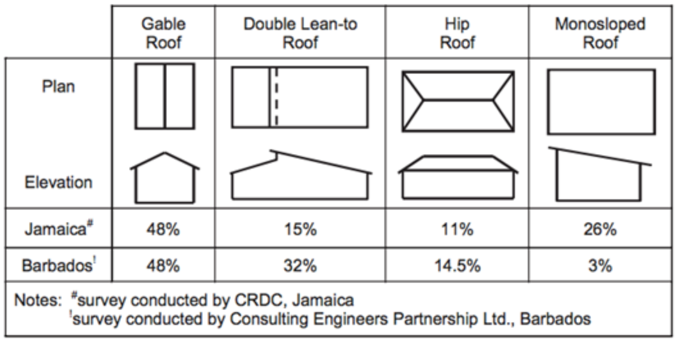
("squatter housing")

2. The early 20th century wood construction (in use today)
3. The modern concrete masonry block wall structures.

A field investigation of residential structures in Trinidad by Prevatt et al. (2010) discovered the most vulnerable construction in the formal and informal housing categories. The formal concrete masonry block structures are generally single wythe walls with vertical steel reinforcement used in some structures and lightly reinforced top bond beams (Figure 2a). Walls of this type typically perform well under wind loading. The more frequently constructed informal houses are built with poorer construction practices with generally little to no construction oversight.

All the basic roof shapes shown in Fig. 3 can be found within the Trinidad housing inventory, with a majority of low-sloped roofs less than 3 on 12. Most homes have relatively large cantilevered roof eaves (Fig. 2b and 2c), extending from 0.9 to 1.2 m (3 to 4 ft), leaving the home more vulnerable to wind failure at the roof-to-wall connection caused by excessive pressurization on the underside of eaves. In contrast, Caribbean islands with increased tropical cyclone frequency (e.g., Barbados) have smaller eaves, on the order of 0.3 m (1 ft). The spacing of 1x roof rafters and purlins ranges from 1.2 to 1.5 m (4 to 5 ft).

Failure of the roof-to-wall connection is the most common failure mode of wind loaded Trinidadian homes (Prevatt et al., 2010 and Prevatt, 1994). In masonry wall construction, the connection developed by wood top plates anchored to the concrete bond beam with toe-nails connecting the roof rafters to the top plates. Damage surveys following Tropical Storm Fran (1990) showed failures in masonry walled homes where, in on damage homes, anchorage between the top plate and bond beam was not provided and, in another, toe-nails were missing between the top plate and roof rafters (Prevatt, 1994). Increased oversight and/or education of the contractor during the construction process would have mitigated these failures in relatively low winds.



	Gable Roof	Double Lean-to Roof	Hip Roof	Monosloped Roof
Plan Elevation				
Jamaica#	48%	15%	11%	26%
Barbados'	48%	32%	14.5%	3%

Notes: #survey conducted by CRDC, Jamaica
'survey conducted by Consulting Engineers Partnership Ltd., Barbados

Figure 3. Common Caribbean low-income house configurations identified in Prevatt et al. (2010)

Acknowledgements

The first author wishes to acknowledge the contributions of his team members University of Florida Graduate students, Tuan Vo and David B. Roueche who prepared the comprehensive report on sustainable housing in Port-of-Spain, Trinidad as a final project in their Engineered Design of Sustainable Residential Structures graduate class.

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An Overview of CariCOOS Wind Mesonet and Wind Modeling Initiative

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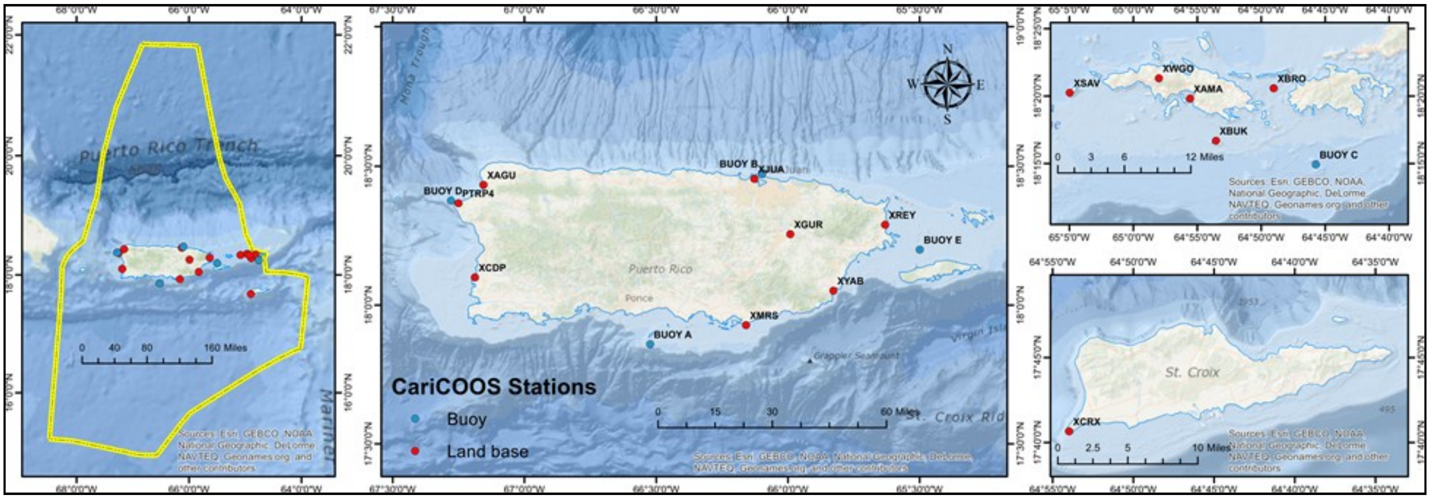


Figure 1. The CaRA region includes the U.S. Caribbean Exclusive Economic Zone for Puerto Rico and U.S. Virgin Islands, as well as that surrounding the small, uninhabited island of Navassa.

Overview

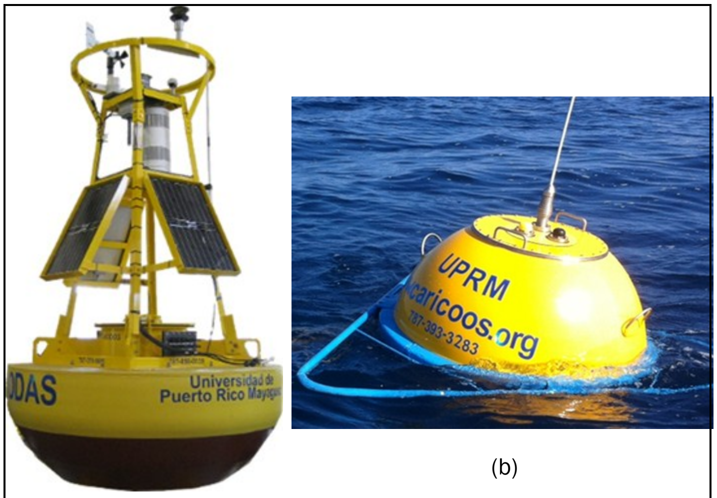
The Caribbean Coastal Ocean Observing System (CariCOOS) is the observing arm of the Caribbean Regional Association (CaRA) for the U.S. Integrated Ocean Observing System (IOOS®). CaRA is one of eleven regional coastal ocean observing system that meets national and regional needs for local ocean observations, data management, and modeling. The mission of CaRA is to establish and administer a sustained observing system for the northeastern Caribbean region (Puerto Rico and the U.S. Virgin Islands) through CariCOOS, providing observations and products for the purposes of detecting and predicting climate variability and consequences, preserving and restoring healthy marine ecosystems, ensuring human health, managing resources, facilitating safe and efficient marine transportation, coastal hazard management response, and predicting and mitigating against coastal hazards. Figure 1 shows the CariCOOS domain composed of the U.S. Caribbean Exclusive Economic Zone (EEZ) for Puerto Rico and the U.S. Virgin Island; in addition it shows the locations of the CariCOOS observing data stations.

CariCOOS/WxFlow hurricane harden wind mesonet

The CariCOOS/WxFlow mesonet consists of fourteen hurricane hardened weather stations, with eight stations distributed along Puerto Rico and six along the U.S. Virgin Islands as shown in Figure 1. The data is collected and transmitted in real-time using cellular communications every five minutes to the Weather-Flow data center and NOAA Meteorological Assimilation Data Ingest System (MADIS). The data is also disseminated to the public and stakeholders through the CariCOOS web site and WeatherFlow data products (i.e. Windalert, a smart phone application).

CariCOOS data buoys

CariCOOS data buoys are equipped with a meteorological package, which includes two anemometers at a height of about 3.5-m above sea level. In addition, salinity and temperature sensors, acoustic current profilers, and directional wave sensors sample suitable oceanographic variables every hour. These buoys are fabricated at the University of Maine's Physical Oceanography Laboratory according to CariCOOS specifications. CariCOOS Buoy A was deployed on the Caribbean coast south of the island of "Caja de Muertos", PR serving the port of Ponce and observing the Caribbean coastal climate; Buoy B, was deployed on the Atlantic coast off the entrance to the port of San Juan, PR.; Buoy C was deployed south of the island of St. John (cruise ship approach) serving USVI; Buoy D a dedicated directional wave buoy, has been deployed in the Mona Passage off the west coast of Puerto Rico; Buoy E will be deploy at the Vieques Sound during the month of May. Figure 2 shows the types of buoys deployed and maintained by CariCOOS personal.



(a)

(b)

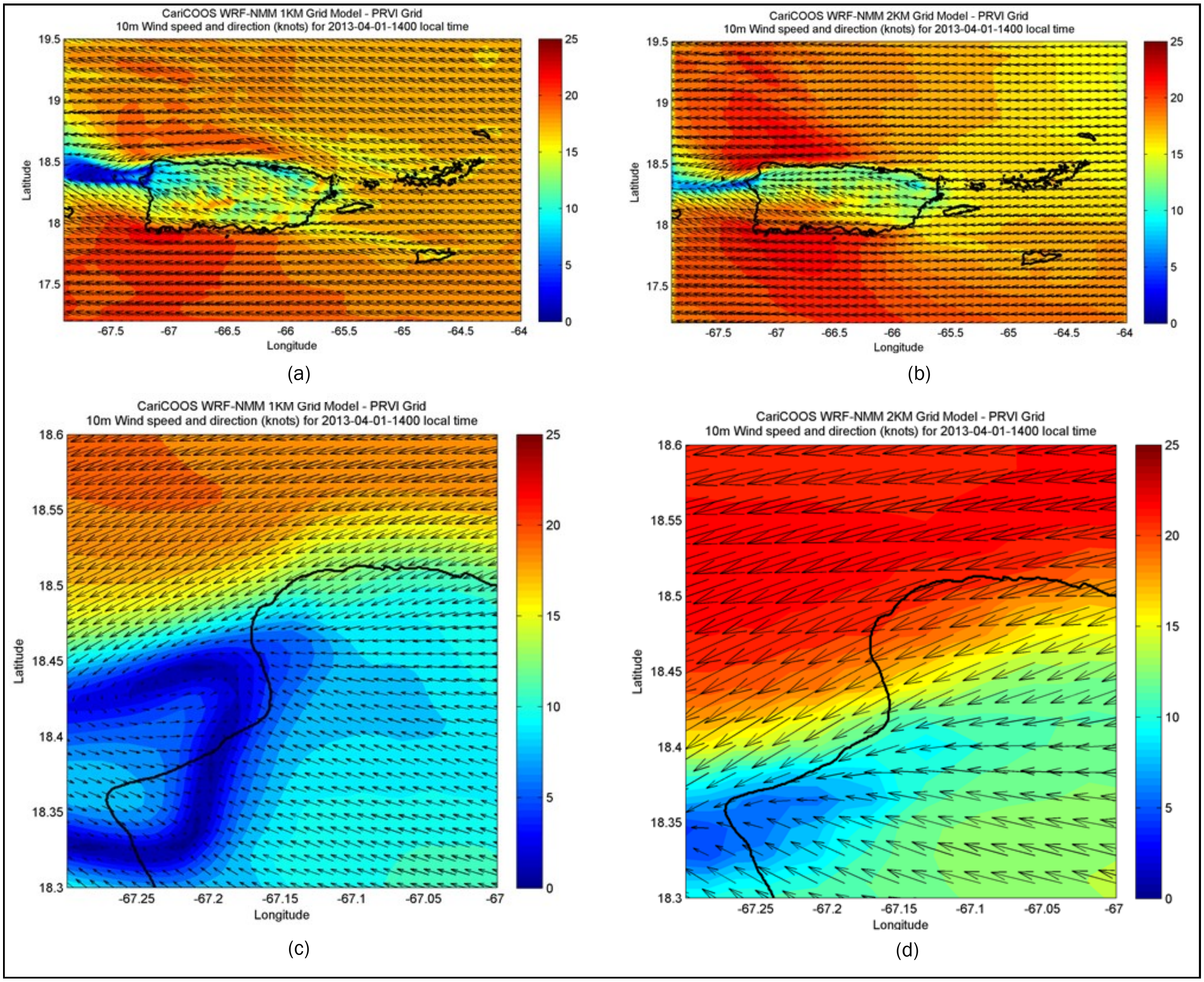
Figure 2. (a) CariCOOS buoys at San Juan, Ponce, USVI and Vieques Sound. (b) Directional wave buoy deployed in the Mona Passage.

CariCOOS modeling products

CariCOOS numerical modeling efforts directly support the local National Weather Service (NWS) San Juan office and other agencies, through model setup, optimization & validation for wind (i.e. *Weather Research and Forecasting* model, WRF) and wave (*Simulating WAves Nearshore*, SWAN) models. Furthermore, such capabilities provide support for safe maritime operations and decision making (i.e. U.S. Coast Guard maritime interest). Coastal inundation modeling also provides crucial information to state emergency management agencies at P.R. and U.S. V.I. for emergency planning. Numerical modeling of coastal currents is also carried out by CariCOOS using a suite of models including ROMS and ADCIRC. At present CariCOOS as implemented a mirror run of NWS current WRF model which is based on the National Center for Environmental Predictions (NCEP) non-hydrostatic mesoscale model (NMM) version 3.1.1.5.1. The model lateral and lower boundary initialization conditions come from the Global Forecast System (GFS), and it consist of two domains: the outer (coarse) domain has 6-km horizontal grid spacing, and the inner (fine) domain has 2-km horizontal grid spacing (Figure 3b and 3d). The model is run four times a day and disseminated on CariCOOS web page. In addition, using similar WRF setup CariCOOS is running a finer spatial resolution of 1-km horizontal grid spacing model (Figure 3a and 3c) using WRF version 3.2.1.5.43 beta. The higher resolution WRF model pursues to provide a more realistic wind filed for the Caribbean region, ongoing work seeks to validate its performance using our wind mesonet data. This effort will lead to improve wave and current model since further improvement of these models depend largely on obtaining more accurate spectral boundary conditions, as well as, better wind forcing, which accurately resolves the daily sea-breeze cycle. More information about the CariCOOS modeling products and real time data measurements are available through the CariCOOS web site http://www.caricoos.org/.

Acknowledgement

CariCOOS is part of NOAA's Integrated Ocean Observing System (IOOS®) Program funded by the U.S. Department of Commerce under Grant No. NA08NOS4730408.



(a) (b)

(c) (d)

Figure 3. WRF model output of 10m Wind speed (knots) and direction valid for 2013-04-01 1400 local time (a) PR-VI 1-km grid (b) PR-VI 2-km grid (c) 1-km grid zoom northwest of PR and (d) 2-km grid zoom northwest of PR

Research on Synchronization and Hurricane Forces on Structures in the Caribbean

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Introduction

When the periodic vortex-shedding frequency of a bluff structure "locks-in" with one of the natural frequencies of the structure, the state is termed synchronization. When this lock in or detuning state persists over a considerable period of time, fatigue stresses become predominant which then may lead to structural damage and even failure.

Vortex-excited oscillations of bluff structures are one of the important problems in wind engineering and wake oscillator models, especially the Van der Pol or Rayleigh type has been studied profoundly over the last twenty odd years. The approach of most researchers is to couple one form of the Rayleigh oscillator with the conventional equation of motion of a single degree of freedom system. It is emphasized though that, depending on the form of the Rayleigh equation chosen, convergence to the solution may not be guaranteed, and the problem becomes ill-defined. Research on semi-empirical models of the coupled Rayleigh wake-oscillator type has been carried out by the authors (Williams et. al 2010).

With the short comings of Wind Tunnels, i.e. the ability to actually represent the Reynolds's number makes experimental work difficult even with the advent of Boundary Layer Tunnels.

With this in mind, analytical solutions are becoming more popular, and the Wake oscillator types has provided some measure of encouragement based on the research.

In addition it allows the study of natural wind phenomenon such as hurricanes to be carried out with little computational effort.

Hurricane Forces on Building Structures

The Caribbean region is prone to annual hurricane events which regularly cause extensive damage to low-rise buildings. Many of the vulnerable structures are residential wooden buildings which are generally non-engineered and perform poorly when subjected to hurricane forces. Factors which also contribute to this phenomenon include; lack of engineering design, unavailability of relevant design data for regional timber species and inappropriate construction techniques for the prevailing environmental conditions. The need for sustained research to improve design and construction techniques in the region has been highlighted previously (Prevatt et al, 2010).

Theoretical and experimental research is being undertaken by the authors aimed at enhancing the hurricane performance of low-rise wooden buildings in region. The focus of the current research is to investigate hurricane wind damage to wooden buildings and develop analytical and numerical models for racking behavior of shear walls and whole house assemblies. Experimental work is being conducted on connections and wall panels constructed from local timber species to develop design data such unit shear, and connection properties to facilitate design utilizing existing codes such as the IBC and NDS2005.

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Figure 2. Model testing

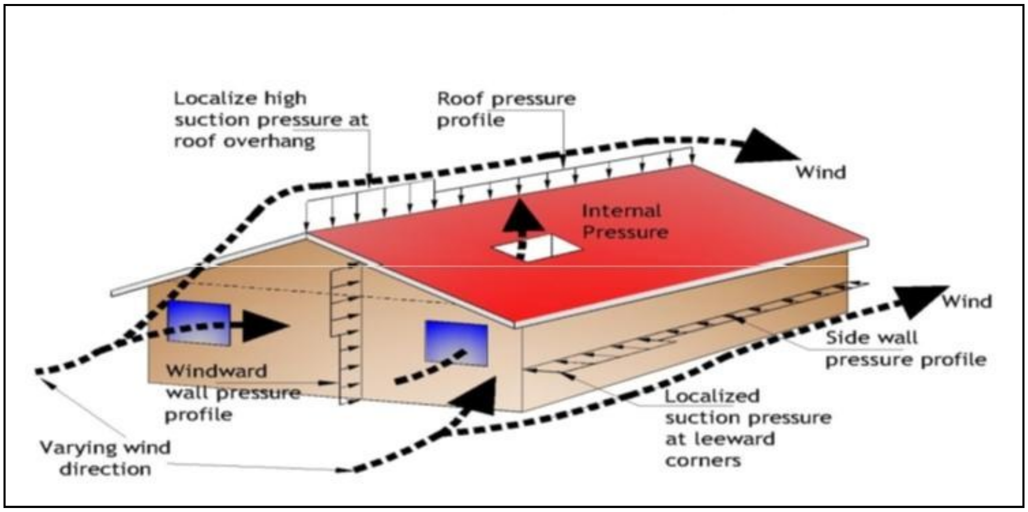

Figure 1. Basic Wind Effects on a Typical Low-rise Building

Wind-resistant Design in an Area of Multiple Hazards

Tony Gibbs, FREng

Regions with Multiple Hazards

There are several regions of the world subjected to multiple natural hazards. World maps of the earthquake regions (Figure 1) and severe cyclonic activity (Figure 2) can be matched to identify the locations affected by both major seismic and wind hazards. They include the Caribbean, in particular, the Eastern Caribbean. In the Eastern Caribbean structures must be located and designed to take into account earthquakes, tsunamis, volcanic activity, hurricanes, torrential rain, storm surge and waves. At the initial project planning stage and the conceptual design stage all of these hazards should be considered simultaneously, not sequentially. In this article it is assumed that the location of the structure is out of harms way with respect to tsunamis, volcanic activity, storm surge and waves. With respect to hurricanes, this article will focus on the wind hazard.

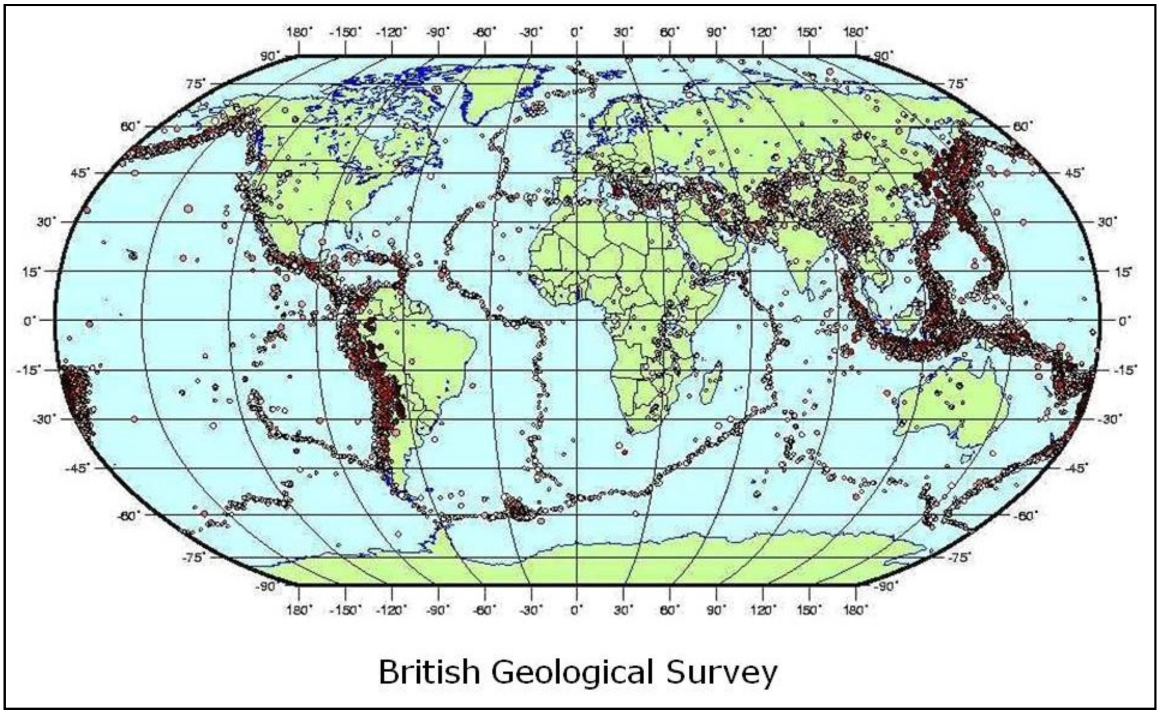

Figure 1. World map of earthquake region (Source: British Geological Survey)

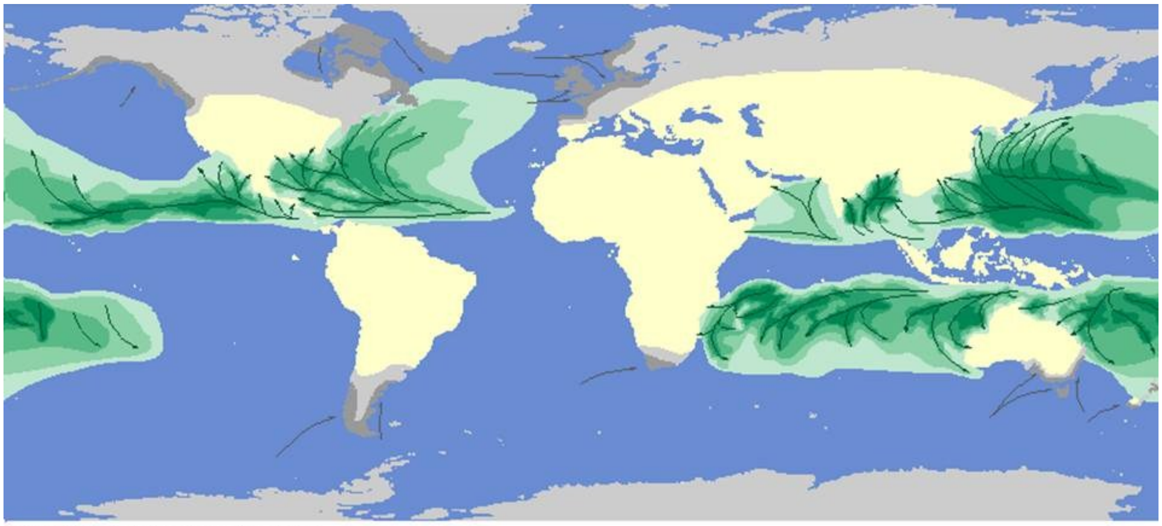

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Figure 2. World map of severe cyclonic activity (Source: Munich Reinsurance Company)

Contradictions and Synergies

In countries with significant seismic activity engineers usually adopt the sequential approach of designing for earthquakes and then checking for wind. Although this practice works, philosophically it is not the preferred way. Designing against multiple hazards is more than doubly difficult when compared with designing against a single hazard, especially when those multiple hazards are wind and earthquake. Some favourable features of wind-resistant design are unfavourable for earthquake-resistant design and vice versa.

- Heavy structures resist winds better. Light structures resist earthquakes better.
- Flexible structures attract greater wind forces. Stiff structures (generally) attract greater earthquake forces.

Both hurricanes and earthquakes impose horizontal loads on structures. Earthquakes can also impose significant vertical loads on a structure. The vertical loading derived from wind is usually significant on parts of a building as determined by aerodynamic considerations. Indeed, most of the damage caused by high winds is due to the vertical component of the wind force.

There are many similarities in the effective design and construction of buildings to resist hurricanes and earthquakes:

- Symmetrical shapes are favourable.
- Compact shapes are favourable.
- There must be a realisation that there is a real risk that “design” forces may be exceeded. This is particularly so in the case of earthquakes where, largely for economic reasons, the design force is deliberately determined to be less than that expected during the anticipated life of the building. This leads to a requirement for redundancy in the structure and for “toughness” – the ability to absorb overloads without collapse.
- Connections are of paramount importance. Each critical element must be firmly connected to the adjacent elements.

There is a basic difference in the performance expectations in the event of an earthquake as opposed to a hurricane. A building is expected to survive its “design hurricane” with virtually no wind damage. Even a catastrophic hurricane should only lead to repairable damage. On the other hand the “design earthquake” is expected to cause (hopefully repairable) damage, and a catastrophic earthquake is likely to lead to a situation where the building cannot be repaired and must be demolished. In such an event success is measured by the absence of deaths and serious injuries. This traditional approach is not favoured by the insurance industry nor by those whose facilities are required immediately after a major earthquake. For those constituencies there is the need to move the goalposts.

Differences

Several differences between hurricane winds and earthquakes as they affect structural design are outlined in the following sections.

- Source of loading – Wind imposes external forces due to wind pressures whereas the earthquake is an inertial force due to ground vibrations.
- Type and duration of loading – Wind storms are of several hours’ duration, loads fluctuate, but predominantly in one direction over significant periods of time. Earthquakes impose transient cyclical loads of, at most, a few minutes’ duration with loads changing direction constantly.
- Predictability of loads – In locations populated for centuries there are usually sufficient historical records to attempt statistical analyses of the wind hazard. The relatively low frequency of damaging earthquakes in any one region makes statistical analysis uncertain with respect to ground vibrations or their effects on structures.
- Influence of local soil conditions on response – This is usually unimportant for wind-resistant design. In the case of earthquakes the response is always governed by soil-structure interaction.
- Influence of topography and ground roughness – These have major effects on the wind speeds (and therefore forces) experienced by structures. Topography can be a consideration in earthquake ground shaking but is not usually a concern of the structural designer. Ground roughness is never a factor in earthquake-resistant design.
- Main factors affecting building response – The external shape and size of buildings affect the level and distribution of wind forces. Dynamic properties are usually unimportant for wind analysis, except for structures with low natural frequency. The response of structures to earthquakes is critically affected by the dynamic properties: fundamental period, damping and mass distribution.
- Normal design basis for the maximum credible event – the conventional approach for wind-resistant design is for elastic response to be aimed at. For earthquakes, inelastic response is permitted by most codes, but ductility must be provided. The analysis is for a small fraction of the earthquake loads corresponding to elastic response. The exception to this is when base isolation or mechanical energy-absorbing techniques are employed.
- Design of non-structural elements – Provided the envelope is not breached, wind loading is generally confined to external cladding components. In earthquakes the entire building (structural and non-structural components) and its contents are shaken and must be designed appropriately.

A clear understanding of these differences is required for the successful design of structures in hurricane regions which are also subjected to the seismic hazard.

PRESIDENT'S CORNER

Greetings! On behalf of AAWE I want to wish all of you a happy and productive 2013. I would particularly like to welcome new members, as well as thank continuing members, both individual and corporate, for their support.

This is my first newsletter as President of AAWE. I'm looking forward to working with you over the next two years to help wind engineering, and our organization, to continue to grow in the Americas region. As I prepared to write this, I heard about a tornado in Bangladesh that took the lives of more than 30 people, injured hundreds more, and was reminded how truly global wind issues are. In this issue we are focussing on wind engineering topics in the Caribbean, from several of our members in that region. I trust you will find this interesting and relevant.

I would like to thank the Board members who have recently completed their terms, Drs. Hector Cruzado, David Prevatt and John Schroeder, as well as our continuing directions, Mr. Steve Camposano, Drs. Anne Cope and Dorothy Reed, for all of their contributions and efforts. I also must thank Dr. Steve Cai who has quietly gone about his work as treasurer for many years. The details he handles truly allows our organization to run smoothly. Finally, I would also like to offer my profound thanks to Dr. Partha Sarkar for all of his efforts as President over the past two years, and also for all of the input he has given to the Board and to me during the transition period over the past few months. So, again, thanks!

Of course, to be successful, we need participation from you, our membership. There are several ways you can participate and contribute:

- First, we will be having an election shortly to fill the 3 empty positions on our Board of Directors and for President-Elect. Please send me your nominations by May 6 for these open positions.
- Second, AAWE is also the sponsor of the 12th Americas Conference on Wind Engineering, held during June 16-20 in Seattle, and organized by Drs. Dorothy Reed and Anurag Jain. Registration is now open; you can find information at the conference website, http://depts.washington.edu/uwconf/12acwe/. It looks to be an exciting event, with many interesting papers and presentations, at a wonderful location.
- Third, we are always looking for articles for this newsletter. Please do not hesitate to send articles on your research findings or interesting projects, or even ideas for special issues, to either Dr. Hector Cruzado (hcruzado@pupr.edu) or to me.

We are interested in ways we can make AAWE more relevant to you and to enhance the implementation of our mission "to promote and disseminate technical information in the research community". If you have any questions or comments about AAWE, please do not hesitate to contact me.

With warm regards,

GREG KOPP

President, AAWE

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Notice to AAWE Membership

AAWE is seeking nominations for its Board of Directors and for the position of President-Elect. Please, send nominations by May 6, 2013 to President Greg Kopp to gakopp@uwo.ca.

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