Assessing the Wind Loading on Elevated Residential Structures with Partially Blocked Ground Floor Areas

Amal Elawady, PhD, Assistant Professor, **Haitham A. Ibrahim**, PhD student,
Extreme Events Institute, an FIU Preeminent Program,
College of Engineering and Computing, Florida International University

David O. Prevatt, Ph.D., Associate Professor,
Engineering School Sustainable Infrastructure and Environment,
Civil & Coastal Engineering Dept., University of Florida

Submitted to:

Mo Madani
Florida Department of Business and Professional Regulation
Hurricane Research Advisory Committee
Florida Building Commission

22 May 2020

1. Introduction

Florida suffers annually from landfalling hurricanes that impose multi-hazards on coastal communities and particularly residential structures that are damaged through flooding, storm surge, and strong winds. Thus, to mitigate flooding and storm surge hazards, the Federal Emergency Management Agency (FEMA) recommends elevating coastal structures to a safe level above the ground level [1]. According to FEMA, houses that were elevated 12 ft above ground were reported safe after the passage of Hurricane Katrina in 2005 [2]. This also agrees with Hurricane Ike damage survey findings [3]. While the safe elevation height is a function of storm surge risks, many areas in Florida houses may be elevated to as high as 17 ft to avoid storm surge damage. There are two considerations of this:

- Elevating houses increases the building's exposure to stronger wind speeds at higher elevations, thus increasing overall wind loading on the building. This is a consideration particularly for existing manufactured houses being raised that may have been designed for a ground-level installation [4-5].
- In addition, an elevated house on concrete or wood piers exposes the underside of its flooring to the wind, and at present, there are no design guidelines in any design code that specify the structural requirements for this component and what is the expected wind pressure distribution on the floor surface.

This proposal seeks financial support to conduct wind tunnel tests on elevated residential structures with partially blocked ground floor areas. Post-hurricane assessments have showed these building types are common in most coastal areas of Florida where they are subjected to both high storm surge and extreme winds. Elevating the houses reduces the risk of damage from storm surge, but little is known about how the elevated areas may change the wind loading produced below the raised floor or how wind flowing through the underside gap affects overall wind loading of the structure.

The Proposers seek support for this work in order to augment an existing Florida Sea Grant - supported research project and to leverage those resources to include the effects of partial blockages of the ground floor level on overall wind loading. The research outcomes will lead to design wind pressure coefficients for better predicting the failure loads on the underside of elevated houses that are used in Florida.

2. Background

Post-hurricane reports by Prevatt et al. [6-7] identified several elevated houses that were damaged by high winds during Hurricanes Irma and Michael. To address this knowledge gap and funded by the Division of Emergency Management (DEM) [13, 14], a preliminary experimental investigation on the aerodynamics of elevated structures has been conducted at the Wall of Wind (WOW) testing facility located at Florida International University (FIU). In addition, a recently initiated project, funded with $285k by NOAA Florida Sea Grant (FSG), is underway to evaluate the wind loading on these elevated structures. The objective of the 2-year Sea Grant project is to identify wind loading distribution patterns on elevated structures through large-scale wind testing.

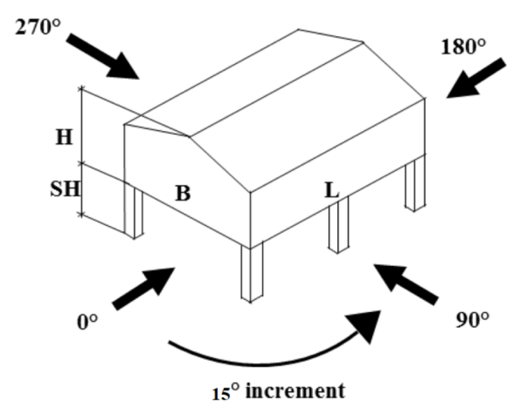
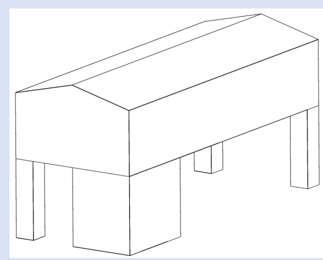
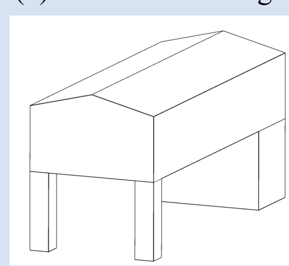
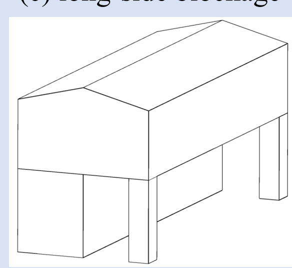
The research will generate results leading to wind load design guidelines and recommendations for residential structures, elevated from 7 ft through 17 ft above ground. The results will be recommended for inclusion in ASCE 7 and the Florida Building Code.

Following the landfall of Hurricane Michael, the Structural Extreme Events Reconnaissance (StEER) Network initiated and executed reconnaissance effort to assess the performance of elevated structures [8]. The data set contains many partially elevated houses, which are elevated houses that have a part of their footprint below occupied by a solid structure, such as storage room or guest room (see Figure 1). Elevated structures have suffered damage, some severely in Hurricane Michael and in Hurricane Irma. Such damage includes different failure modes such as wall cladding damage, floor cladding damage, roof damage, pile damage, and total collapse. Figure 2 shows the ripping-off failure mode of the underside parts of the partially elevated houses [8-9].

The ongoing FSG research project will investigate the wind loading on elevated residential structures. However, the unique case of wind loading acting on partially elevated houses is not part of the scope. *The PIs hypothesize that the asymmetric ground floor blockage area below an elevated residential structure modifies wind flow patterns and alters wind load (magnitudes and/or distributions) on these buildings. The presence of these blockages may increase or decrease the overall vulnerability to damage during extreme wind events*. This project proposed herein offers an opportunity to learn whether such blockages affect wind loading, and possibly to optimize the locations of ground floor blockages.

The PIs plan to leverage the support from an existing project to conduct additional experiments to achieve solid conclusions about the aerodynamic behavior of these houses. The plan is to address a common building typology of the Florida Keys. By doing this in conjunction with the ongoing FSG project, we would ultimately save considerable costs compared to if it would have to be done separately. Table 1 shows test cases for the completed DEM project [13, 14], the ongoing FSG project, and the proposed cases that can be tested, if funded.

Table 1. Aerodynamic test cases for slab-on grade, elevated and partial elevated houses at WOW.

Test Phase	Aspect ratio (L/B)	Length (L) (ft)	Width (B) (ft)	Height (H) (ft)	Column height (SH) (ft)	
DEM project (Completed [13, 14])	1.38	29	21	12.5 21.5	0, 2, 7, 12	
FSG (Ongoing)	2.0	40	20	12.5	0, 7, 12, 17	
	2.5	50	20	12.5	0, 7, 12, 17	
Proposed Scope to FBC (partial elevated houses)	2.5	50	20	12.5	12	(a) corner blockage  (b) short-side blockage  (c) long-side blockage 

Note: Dimensions represent the full-scale model. A length scale of 1:5 will be used for testing.

Figure 1. Typical partially elevated houses in Florida.

Figure 2. Ripping-off of the underside parts of the partially elevated houses recorded in Florida after the landfall of Hurricane Michael and Irma [8-9].

3. Research Significance

A total number of 312 elevated residential structures impacted by Hurricane Irma in the Florida Keys were surveyed; among these, a number of 230 houses had ground floor structures that partially block wind flows beneath the elevated floor [9]. Thus, it is of great significance to understand how these partially elevated houses will perform in extreme wind events, which in turn can help in minimizing the losses from future hurricanes.

Although ASCE 7-16 [10] and Florida Building Code (FBC2017) [11] provide comprehensive provisions to calculate wind loads on most structures, up to the PIs' knowledge, both the ASCE 7-16 and FBC2017 do not provide information about the aerodynamic behavior and wind loading of the elevated/partially elevated structures. To take a further step towards achieving resilient coastal communities, the main goal of this proposal is to better understand wind actions on this type of structures during extreme wind events such as hurricanes.

4. Objectives

The main objectives of the proposed research are: (1) assess wind distribution patterns on partially elevated structures through large-scale wind testing; and (2) investigate whether current design provisions provided by the FBC [11] and the wind loading provisions provided by the ASCE 7 [10] for slab-on-grade low-rise structures are adequate for the case of partially elevated houses.

The proposed research will focus on identifying wind loading on the underside of the floor (which does not exist in slab-on-grade ones) and how the wind pressure on the floor will be affected when additional parts/rooms are added beneath the floor. Ultimately, at the conclusion of the FSG results in 2022, we will be able to compare the wind load distribution on the surfaces of slab-on-grade, elevated, and partially elevated structures by leveraging the results obtained from completed, ongoing, and proposed set of aerodynamic testing. The outcomes of the proposed research will augment the aerodynamic database of elevated structures currently being produced at the WOW facility at FIU [12, 13, 14] by including the partially elevated models. This research will enable for enhancing the design considerations for evaluated houses throughout the State of Florida.

5. Tasks

To achieve the objectives of this project, the following three tasks will be followed:

a) Model selection

Available data from prior post-hurricane damage surveys will be used to determine the common geometry of the existing partially elevated houses and select building case for wind testing as explained in task (b).

b) Large-scale wind tunnel testing of partially elevated residential structures

The proposed research will utilize the WOW facility at FIU to carry out large-scale aerodynamic experimental studies on the selected models shown in Table 1. Among eight natural hazard testing facilities with only two specialized in wind-related studies, the WOW has been named as a national Experimental Facility under the Natural Hazard Engineering Research Infrastructure (NHERI) program of the National Science Foundation (NSF). The WOW is a one of a kind open-jet hurricane simulation facility that is capable of simulating wind speeds up to Category 5 hurricane winds of 157 mph on the Saffir-Simpson scale. The WOW is equipped with 12 electric fans arranged in an arc shaped intake that produce a relatively large wind field of 20 ft. wide and 14 ft. high which enables testing of large-scale models.

Figure 2. The 12-fan and floor roughness elements of the Wall of Wind (WOW) facility.

For this proposal, three models are selected for the experimental tests. Each model represents a one-story partially elevated house with length to width ratio of 2.5. In the ground floor, blocks with a footprint area ranging between 20-50% of the house footprint area will be used to simulate the slab-on-grade storage/guest rooms in these houses. To understand role of the location of the on-ground room, three locations of the blocks will be considered (long side, short side, and corner blockage) as illustrated in Table 1. It should be noted these models might be refined based on the results obtained from task (a). The surfaces of the test models including walls, roof, underside floor, will be instrumented with 384 densely distributed pressure taps connected to Scanivalve pressure devices to collect pressure time histories. Cobra probes will be used to measure the wind speed profile during the tests. Various wind directions will be considered by rotating the automated turntable at the testing chamber of the facility.

c) Data analysis

In this task, wind pressure data collected from the pressure taps distributed on the surfaces of the test models will be analyzed to investigate the overall pressure distributions on the partially elevated houses and to determine the localized suction on the underside parts. Estimated peak pressures will be normalized to calculate peak pressure coefficients using the 3-sec gust wind speed recorded at the roof mean height. In addition, area-averaged pressure coefficients will be calculated according to the zoning guidelines provided in the Components and Cladding chapter in the ASCE 7-16 standard. Observed changes in local and area-averaged peak pressure coefficients on the building surfaces for each case will be reported. Also, comparisons with ASCE 7-16 pressure coefficients for the case of the slab on grade building model will be done.

6. Deliverables

An interim report (e.g. in March) and final report at the end of project (e.g. June) will be provided. The reports will include description of the test procedure, data collection, and the analysis. The results will include wind pressure contour maps (for the roof, walls, and underside floor with the blockage area) and design guidelines to account for wind actions on partially elevated structures. Such knowledge (i.e., pressure contour maps and pressure coefficients) are currently missing in both the ASCE 7-16 Standards and FBC. Comparisons between the test configurations will be articulated. For future work, the pressure contour maps can be leveraged to interpret reasons for the observed damage in the structural and non-structural components of the partially elevated houses. The outcomes of the proposed research will advance the fundamental knowledge and address current science gaps related to the aerodynamics of existing coastal partially elevated houses.

7. Budget

The Wall of Wind at FIU is solely responsible for the satisfactory performance of the tasks and completion of the deliverables as described in this Scope of Work. Failure to complete the tasks and deliverables in the time and manner specified in Sections 3 and 4, respectively, shall result in a non-payment of invoice until corrective action is completed as prescribed by the program or contract manager.

The budget for this project is $150,000 to cover two weeks of testing at the Wall of Wind facility, all personnel salaries, material purchasing, and recharge center costs.

8. References

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