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September 11, 2009

Ms. Shemeeka Hopkins
Residential Construction & Mitigation Program
Division of Emergency Management
2555 Shumard Oak Boulevard
Tallahassee, FL 32399-2100

RE: FINAL REPORT
Contract # 09RC-23-13-00-05-194

Dear Ms. Hopkins:

I am pleased to enclose our final report for the research project ***Hurricane Loss Reduction for Housing in Florida*** conducted by the International Hurricane Research Center (IHRC) at Florida International University (FIU). This report summarizes our research activities from July 1, 2008 through June 30, 2009. This report complies with the required reporting requirements per the contract agreement.

The IHRC team looks forward to continuing to work with you and to be of service to the residents of our state. Please contact me if you have a questions or comments.

Sincerely,

Stephen Leatherman
Principal Investigator

International Hurricane Research Center

FLORIDA INTERNATIONAL UNIVERSITY

A Resource for the State of Florida

HURRICANE LOSS REDUCTION FOR HOUSING IN FLORIDA

<u>FINAL REPORT</u>
For the Period July 1, 2008 to June 30, 2009

A Research Project Funded by
The State of Florida Division of Emergency Management
Through Contract # 09RC-23-13-00-05-194

PREPARED BY
THE INTERNATIONAL HURRICANE RESEARCH CENTER
FLORIDA INTERNATIONAL UNIVERSITY

Final Report

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Executive Summary

Structural mitigation can result in significant hurricane loss reduction. Recent research indicates that improving the resiliency of the building stock located in hurricane-prone regions can markedly reduce loss and damage. In the aftermath of Hurricane Charley, post-disaster assessments indicated that insured losses for structures built under the 2002 Florida Building Code (FBC) were as much as 40-50% lower than equivalent homes built to the Standard Building Code (SBC). The Residential Construction Mitigation Program is making a critical contribution to the State of Florida by ensuring that the built environment will have a better chance of surviving future impacts from hurricanes. Continued RCMP funding has allowed the development of an innovative research capability in full-scale structural testing to determine inherent weakness of structures when subjected to hurricane-force winds and rain. The Wall of Wind testing apparatus permits a fundamental understanding of the failure mode of building and designs and hence lead to technologies and products to mitigate hurricane damages.

Current testing practices are limited to evaluating individual building components such as doors, windows, shutters, etc. These tests are inherently limited due to the absence of a holistic “building systems” approach to the analysis. The main drawback of current testing facilities and their simplified test procedures is that the components are not treated as integral members of the building system and thus cannot be expected to behave the same as they would as a part of the entire building structure subjected to the brunt of a hurricane. Full-scale wind testing is the missing component for a comprehensive hazards testing facility at FIU.

This executive summary highlights research findings discovered through the dedication of FIU faculty and students while using the Wall of Wind full-scale testing apparatus. The below sections summarize stated objectives for the 2008-2009 research period.

Annual Report to the Florida Legislature

The IHRC assisted the Division of Emergency Management in the preparation of the annual report and accounting of activities under section 215.559, Florida Statutes, Residential Construction Mitigation Program. The report was submitted by DEM to the Speaker of the House of Representatives, President of the Senate, and the Majority and Minority Leaders of the House of Representatives and Senate on January 1, 2009.

Roof and Wall Vents Study under Simulated Hurricane Winds

Typical households have a balanced ventilated wall and roofing system. During sever weather events vents are subjected to wind loading and can be the path for water infiltration during hurricane events. Very limited research has been performed on water intrusion through various types of vents under differential pressures. This research effort focused on the performance of vents under simulated hurricane effects.

Florida Building Code (FBC, 2007 – Section 1523) defines the minimum testing requirements for substrates, roofing components, roofing systems and roofing assemblies. The current study was based on full-scale holistic testing of roof vents which provides advantages over component testing as the whole building structure incorporated with vents is subjected to wind and a wind-driven rain field engulfing the structure and thus producing realistic aero and hydrodynamic effects. A full-scale model representing a typical single-story building was constructed. Roof and wall vents were installed on the building model. The Wall of Wind (WoW) (6-fan system) was used to determine wind forces and water intrusion through the vents. Tests were performed with and without wind-driven rain. Failure modes and water intrusion through different kinds of vents were studied and correlated to the wind speed and wind-driven rain intensity.

The tests indicated that water infiltration through a vent system is dependent upon the differential pressure as well as the vent mechanism. For vents experiencing higher differential pressures, covers can be used during storms to reduce water infiltration. Active controls can also be designed to close the vents automatically as differential pressure increases based on the wind speed and wind angle of attack.

The goose neck vent has maximum water infiltration when the opening on the gooseneck vent faces the wind, which allows maximum pressure differentials for angles of attack between 45 through 90 degrees. It is recommended that the goose neck vent should be covered during storms to reduce water infiltration. The ridge vent differential pressure coefficient is minimal and water intrusion was minimal. The relationships obtained between the Reynolds number and the drag coefficients or pressure coefficients remained comparable with previous studies.

Full-Scale External and Internal Pressure Measurements on Low-Rise Building Roofs

In this project, a wind induced internal and external pressure in typical low-rise building models was investigated primarily by using the Wall of Wind full-scale wind testing facility. The effect of different dominant openings (door and window), vents (gable end, goose neck, turbine, and soffit) and background leakage under different wind angles of attack are carried out. Prior to performing the full-scale analysis, a three tier approach comprising (i) a computer simulation and (ii) small-scale WoW (1:8 replica of the full-scale WoW) followed by (iii) a confirmatory test using the full-scale WoW was used to assess the effect of blockage and proximity to the WoW flow simulator.

The outcomes of the small scale WoW analysis was compared with the results of the numerical computation and previously carried out researchers from literature. Both the numerical and small scale WoW test results indicated the importance of blockage and proximity effect and the need for further study at full-scale. These blockage and proximity effect studies resulted in the selection of an optimal low-rise building test model dimensions (i.e. 9ft L by 7ft W and 7 ft H) and testing location (i.e. the test model placed at 12 ft from the WoW) that provides aerodynamically sound data.

A low-rise building model with interchangeable gable and hip roofs was designed and fabricated. Detailed multiple dominant openings (doors with secondary openings and windows), ventilation openings, vertical (ceiling) and horizontal (partition wall) compartments were fabricated. These details enabled researchers to study (i) the impact of the fluctuation of external pressure over the internal pressure, (i) the intensity of critical internal pressure that builds up as a consequence of compartmentalization and various opening sizes of dominant openings (iii) the influence of ventilation openings in dampening the internal pressure excitation and (iv) the net roof design wind load that generates as a result of coupling of the attic internal pressure and roof external pressure.

It is shown that the fluctuation in external pressure is highly correlated to of the fluctuation in the internal pressure. Findings also confirmed that partitioning of the building has a significant impact in the variation of the intensity of internal pressure and hence the net envelope design wind load. Moreover, it was determined that the size of dominant openings (i.e., door and window porosity ratio with respect to windward wall) influences the level of internal pressure that develops both in the attic and living room of a low-rise building.

Performance of Gable End Wall Bracing Retrofit for Hurricane Protection

The Florida Building Commission (FBC) has proposed new provisions to provide prescriptive solutions for retrofitting gable ends of existing buildings. The prescriptive solutions are designed to strengthen gable ends in existing buildings by bracing the gable end trusses at 24 inch on center. The retrofits are designed to provide economical, simple, and practical solutions to reduce the vulnerabilities of gable ends to Category 3 and stronger hurricanes.

Although the prescriptive solutions can provide the retrofitted gable ends with "the strength equal to the structural provisions of the latest building code requirements for new buildings", they are based on engineering calculations that may or may not reflect the actual conditions of existing buildings. There are many unforeseen problems (such as undersized studs and/or permanently attached obstacles) that prevent the horizontal braces to be correctly installed. While these problems are addressed in the revised provisions, the solutions may alter the load path causing the building to be subjected to torsion or other modes of failure that are not accounted for in the design of existing buildings. Moreover, the retrofitted gables ends could become significantly stronger than the connections that tie down the wall and/or the roof, which deviate the failure from the gable ends to other components of the buildings. Thus, there was a need to better understand the ultimate load carrying capacity of gable ends in existing buildings and the performance of the prescriptive solutions through full-scale structural testing.

This research project investigated two different retrofit systems: (1) X-bracing and (2) C-bracing to determine their structural performance under hurricane wind. ASCE 7-05 "Minimum Design Loads for Buildings and other Structures" load test was used to establish the level of performance of the retrofit systems of the gable end walls, the weak spots and failure mechanisms of the retrofits of the gable end wall. Full-scale testing was performed using a jack and pump system as a concentrated load at the center of gravity of the gable end wall.

Research confirmed that the C-brace system performed the best and is the only system tested that can withstand the designed wind load acting on the gable-end wall of 2340 lb. However, this is only true if the sheathing is not present (blown off). For a fully covered sheathing system, there is no significant deviation between the C-bracing or X-bracing retrofit systems. In fact, the failure mode seems to be controlled by the sheathing failure. It was determined that the damage in the gable-end wall could be minimized if the sheathings are properly secured. Thus, any new technology that could prevent the sheathing from detaching from the trusses will also prevent gable end wall failure.

Performance of Clay and Concrete Roof Tile Systems

Windborne debris has been established as a principal cause for the breaching of the building envelope during windstorms. An opening on the windward face of the building can lead to failure by allowing positive pressures to occur along with negative external pressures. Only 5% of opening on the windward wall of a building is enough to allow full internal pressurization that effectively doubles the pressures acting to lift the roof and push the side wall. Based on Minor and Behr (1994) observations after hurricane Andrew (1993), glazing systems performed poorly, largely due to the impact of windborne debris and damage to building contents was extensive. To preserve the integrity of the building envelope, cladding systems must be able to sustain impacts from the debris and cover openings for the duration of the storm.

Due to the complex nature of missile and debris impacts, there are no design criteria that can be used to calculate the static force of a wind missile impact. In order to determine adequate missile impact resistance for a building, the designer has to use the performance criteria of the wall, door, window, or roof section found through missile impact testing. The purpose of this research was to identify and assess the effect of roof tile wind-borne debris on different building components, such as shuttering systems, windows, and other vulnerable structural and non-structural components.

From parametric studies it was observed that roof tiles can become wind borne debris at a category 1 hurricane and higher. The maximum stress values for steel and aluminum at the location of impact were found to be in the elastic range due to this there was no permanent deformation observed; hence these materials are recommended for all category wind speeds for this size debris (2 inch diameter concrete roof tile). Based on the research findings it was concluded that the impact of compact windborne debris on cladding components is not negligible, despite its less drag coefficient compared to other forms of debris.

Education and Outreach Programs

The education and outreach components initiated this year built on the foundation of research and work predominately conducted during previous grant periods. Efforts this year were made to increase the level of awareness among the general public regarding the need for decreasing the vulnerability of building structures to hurricane-force winds. Partnerships were made with local and statewide organizations to coordinate interrelated activities and ensure cooperation among parties implementing hurricane loss reduction activities. Memoranda of

Understanding continued with the Federal Alliance for Safe Home (FLASH) and the Disaster Survival House (DiSH). In addition the team continues to maintain a web page for the Laboratory for Wind Engineering Research under the URL: ***http://www.ihrc.fiu.edu/lwer/***.

Researchers attended the Governor's Hurricane Conference to ensure that businesses, organizations, and agencies were aware of on-going research activities conducted through the RCMP program and the applications of this research to personal mitigation strategies. An exhibit booth allowed IHRC staff to answer questions and distribute information about research initiatives related to the topic of hurricane loss mitigation.

Researchers from the IHRC had continuous interaction and participation in the activities of the Miami-Dade County Local Mitigation Strategy (LMS) Working Group. IHRC representatives made several presentations throughout the year on issues related to hurricane loss mitigation, in general, and to the RCMP, in particular. The IHRC hosted several K-12 tours for local schools allowing the students to see research conducted with the Wall of Wind testing apparatus.

IHRC Project Research Team

The 2008-2009 research team was comprised as follows:

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