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August 30, 2007

Ms. Iris Stanley
Division of Housing and Community Development
Florida Department of Community Affairs
2555 Shumard Oak Boulevard
Tallahassee, FL 32399-2100

RE: <u>FINAL REPORT</u>
<u>Contract # 06RC-A%-13-00-05-261</u>

Dear Ms. Stanley:

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, 2006 through July 31, 2007. 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
Director

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A Resource for the State of Florida

HURRICANE LOSS REDUCTION FOR HOUSING IN FLORIDA: EXECUTIVE SUMMARY

<u>FINAL REPORT</u>
For the Period July 1, 2006 to July 31, 2007

A Research Project Funded by
The State of Florida Division of Emergency Management
Through Contract # 06RC-A%-13-00-05-261

PREPARED BY
THE INTERNATIONAL HURRICANE RESEARCH CENTER
FLORIDA INTERNATIONAL UNIVERSITY

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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). According to the preliminary estimates by the FIU Public Hurricane Loss Model, the reduction in ground-up loss can be as much as 70% for category 3 hurricanes. Obviously, much more can and must be done to make Florida resistant to hurricane impacts, greatly reducing the cost to homeowners, businesses, and government.

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 will permit a fundamental understanding of the failure mode of buildings and hence lead to technologies and products to mitigate hurricane impacts.

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.

The full-scale wind testing facility at FIU will be able to capture the intricate flow separation, vortex generation, and re-attachment phenomenon around and downwind of edges and corners of test models. Thus, while other information on pressure data (such as positive pressure values on the windward face) could be effectively determined by wind tunnel experiments, the flow phenomenon effects can only be determined by experiments in a full-scale wind testing facility.

The 2-fan Wall of Wind apparatus, previously funded by Florida Division of Emergency Management, has already been successfully used to test roofing shingles and soffits in partnership with the Institute for Business and Home Safety (IBHS) and Univerity of Florida (through 2005-2006 Residential Construction Management Program funding). Based on this proof-of-concept, Renaissance Reinsurance Holdings, Ltd., the largest re-insurer of hurricane-prone areas in the world, commissioned the building of a 6-fan array, which can generate a 130 to 140 mph wind field utilizing flow constriction. The development and construction of the RenassianceRe Wall of Wind began in 2006 based on design work and assistance from Emil Simiu, NIST Fellow and now FIU Distinguished Research Professor.

The IHRC is presently constructing a building to house the WoW testing apparatus on the FIU Engineering campus. The RenaissanceRe Wall of Wind is expected to be operational in Fall 2007. This advancement will provide valuable experience and insights for further research and development regarding full-scale testing.

Surface-level hurricane wind data, collected through the Florida Coastal Monitoring Program (FCMP), will be used to simulate a wind field that reasonably represents hurricane wind characteristics for the Wall of Wind, thus making WoW testing realistic. FIU is a current FCMP partner with funding provided through the Florida Hurricane Alliance as led by the IHRC. The IHRC team has high-resolution surface wind data collected during many hurricanes (e.g., Isabel, Francis, Ivan) which is currently being analyzed to evaluate wind mean and turbulence characteristics, including mean wind speed, gust factor, turbulence intensity, integral length scale and turbulence spectra. Such data will be used as targets for simulating the hurricane-force fluctuating winds in the RenaissanceRe Wall of Wind facility.

The aerodynamic pressure coefficients obtained from the Wall of Wind testing will be compared to wind tunnel pressure data available from University of Western Ontario (UWO), Texas Tech University (TTU), Colorado State University (CSU), Rowan Williams Davies & Irwin, Inc. (RWDI), and National Institute of Standards and Technology (NIST). Wall of Wind pressure results will be also compared with reliable full scale pressure time history data from TTU Wind Engineering Research Field Laboratory (WERFL) test building. In addition the IHRC is working with the University of Arkansas to conduct computational fluid dynamics modeling to improve the performance of Wall of Wind which will further enhance research testing.

This executive summary highlights research findings discovered through the dedication of faculty and students over the past year. Periodic communication via e-mail and telephone conferences has also contributed to keeping our effort on target and within established timelines. The below sections summarize stated objectives for the 2006-2007 research period.

Annual Report to the Florida Legislature

The IHRC assisted Division of Emergency Management (DEM) in the preparation of a full 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, 2007.

Full Scale Simulation of Wind, Water and Structural Interaction

Mitigation of Roof Uplift Through Vortex Suppression Techniques

In an effort to reduce the catastrophic effects of hurricane-force winds on residential and commercial roof structures, several studies were conducted to observe the effects of surroundings and alternative roof geometries on vortex generation. This innovative field of research is appropriately entitled "vortex suppression" as methods are currently being sought to disrupt and deflect the conical vortices from the roof structure to drastically reduce the effects of the extreme vortex-induced roof suctions. It is widely believed that simple modifications in the shape of the roof edge may drastically reduce vortex generation as well as associated damage. The objective of this study was to assess the effectiveness of modified roof edge geometry in the reduction of high suction pressures at roof corner and edge regions through full-scale testing approach. Utilizing the RenaissanceRe 6-fan Wall of Wind (WOW) testing apparatus, a test structure instrumented with pressure transducers was equipped with six different modified roof edge geometries and subjected to hurricane-force winds. A series of seven tests--six for the different roof geometries and one to determine the standard pressure distribution without any modifications--were conducted, and pressure data from all seven tests were compared. Results indicated that the use of such mitigation devices resulted in an average reduction in uplift by about 50%, with the largest reduction observed from the Flat Roof AeroEdge Guard which yielded 74% decrease in the worst suction in the corner region. Testing was also performed to identify the wind speeds at which the conical vortices became strong enough to start scouring different types of roof gravel. These results offer new hope for further development in the area of hurricane structural damage mitigation.

Rooftop Equipment Wind Load and Its Mitigation for Buildings in Hurricane-Prone Regions

Rooftop equipment is a general term used to describe components such as condensers, exhaust hoods, HVAC units, and communications equipment that are typically mounted on the roof of structures. This type of equipment is subjected to wind loads that must be considered when designing the anchorage connection between the particular component and the roof. Damage reconnaissance studies conducted during the 2004 and 2005 hurricane seasons witnessed widespread rooftop equipment failures. The aim of this research was to develop mitigation techniques that will reduce the wind loading on mechanical rooftop equipment and the forces transferred to the roof supporting structure by the equipment through the use of aerodynamic retrofits such as the installation of wind screens.

Results for a single-story building located in Exposure C open terrain indicated that the difference in wind loading on rooftop equipment for a Category 4 hurricane versus a Category 1 hurricane is approximately 58%. The difference in wind loading on rooftop equipment for a Category 3 hurricane versus a Category 1 hurricane is approximately 38%. Findings also showed that a wind screen has a potential of reducing the effect of wind loading by *two to three hurricane categories* (i.e., Cat 3 to Cat 1 on the Saffir Simpson Hurricane Scale) and thus can prove extremely helpful to reduce rooftop equipment damage. The wind screen retrofit technique may cost approximately 20% of the actual equipment, structural framing, and installation. In addition to preventing damage of rooftop equipment, such retrofit techniques will have other advantages such as (i) prevention of roof damage, (ii) elimination of water infiltration thus preventing losses to building contents, mold growth, dry wall saturation, (iii) prevention of windborne debris that may result from detached rooftop equipment.

Development of Effective Roof-to-Wall Connections for Low-Rise Buildings to Withstand Hurricane Wind Loads – Phase 1

Catastrophic losses due to hurricanes are the largest and most pervasive risk faced by the US coastal communities from Maine to Texas. Hurricanes of the last few years have not only cost thousands of lives and billions of dollars of damage, but most notably shredded public belief in the safety of its built environment. The growth of hurricane-induced losses from $1.3 billion per year pre-1990 to $36 billion per year post-2000 (National Science Board, 2007) is a direct result of over 50 years of accumulated decisions to invest in physical infrastructure and community development on the seaboard, where now 50% of the US population lives within 50 miles of the coastline (National Academy of Sciences, 1999). With losses surpassing $100B in 2005 (http://www.nws.noaa.gov/om/hazstats.shtml) and over 1,400 fatalities in 2004-05 (Govt. Accountability Office Report, 2006), hurricanes have far-reaching societal and economic impacts. As a societal need and engineering problem, hurricane loss mitigation is a continuing challenge of a multidisciplinary nature.

Engineered structures are vulnerable to damage from hurricane-induced wind, rain, and debris, though the combined impacts are not well understood. Damages during these extreme wind events highlight the weaknesses inherent in coastal residential building construction and underscore the need for improving their structural performance. The objective of this research is to develop a novel, cost-effective, light, strong, ductile, and non-intrusive roof-to-wall connection system using high performance fiber composite materials (as an alternative to conventional intrusive connections) through full-scale testing under simulated hurricane effects and Performance Based Design (a concept well embraced by the earthquake engineering community). The project will assess the structural and economical feasibility, constructability, and performance of the proposed connection system through detailed experimental and analytical investigations including non-linear effects.

During this research cycle faculty and students performed a (1) detailed literature review of intrusive hardware type roof-to-wall connections – such background knowledge will be used as a baseline for the actual development of the non-intrusive roof-to-wall connection system, (2) concept development for the novel non-intrusive roof-to-wall connections and (3) formulating methodology for developing the innovative connection system.

Performance of Tile Roofs Under Hurricane Impact – Phase 2

In the past few years, the State of Florida has suffered the impact of an unprecedented number of hurricanes, resulting in an immense regional and local economic impact. The damage from some of the rather smaller hurricanes (e.g. Hurricane Wilma) has challenged the building codes in South Florida as they relate to roof covering. While most homes suffered little structural damage, many experienced roof covering failures, and especially a large number of roof tiles.

The main issues are: (a) whether there is a significant difference in performance of clay and concrete tiles under different attachment methods, (b) whether the current building codes provide adequate and reasonable measures for proper performance of tile roofs and (c) what, if any, change is necessary to improve the way tile roofs are installed.

A detailed experimental and analytical study was carried out for field and ridge tiles using a combination of clay or concrete with adhesive-set or mortar-set. The strongest system appeared to be concrete tiles with mortar when subjected to mechanical uplift and simulated wind load testing. While concrete tiles bond to mortar much better than clay tiles, clay tiles adhere better to the foam. In Model 1b (clay tiles with foam), the roof tiles began to fail after being subjected to 120 mph wind speeds for 3.5 minutes. However Model 4 (concrete tiles with mortar), the roof tiles remained firmly attached to the roof with no visible damage to any of the tiles for the same duration of testing. Studies also showed that concrete tiles are 39% stronger than clay roof tiles in resisting impact by a projectile during a hurricane. The present study does not support recent efforts by the industry to completely ban the use of mortar for all attachments of hip and ridge tiles. However, it is suggested that any such ban on mortar be limited to clay tiles only.

Roof tile failures seem to initiate at the eave on the windward side of the roof, after which a progressive domino failure pattern was observed. Setting pattern of the tiles may also help develop a better inter-locking arrangement for the entire roof. Workmanship was found to be the main contributing factor to roof tile failures, as confirmed by tests and analysis.

Specific recommendations arising from this detailed study on the performance of tile roofs under hurricane impact are twofold:

- Special attention should be paid to the attachment of eave tiles, as they are the most vulnerable to failure, and as their failure can result in loss of a large section of the roof.
- Inspection procedures should be put in place to ensure roofing contractors closely follow the standard techniques of roof tile installation, as poor workmanship was found to be the main contributing factor to roof failures.

Computation Fluid Dynamic Modeling to Improve the Performance of the Wall of Wind – Phase 1

A turbulence simulation system to reproduce conditions in the Atmospheric Boundary Layer (ABL) is needed to improve the performance of the Wall of Wind (WOW) full-scale testing apparatus. This can be achieved by using a system of rudders located directly in front of the propellers that are controlled and moved within a certain range to create turbulence. A computational fluid dynamics (CFD) analysis is needed to determine a more efficient configuration of the WOW system including the size of the rudders and the range of motion necessary to create such turbulence conditions. The IHRC subcontracted with a national expert in CFD at the University of Arkansas to assist with this research. Four separate contraction designs were considered with varying gaps between the Wall of Wind fan units. It was found that the increased gap width reduces the volumetric flow rate (discharge) in every fan unit.

Programs of Education and Outreach to Convey the Benefits of Various Hurricane Loss Mitigation Devices and Techniques

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/***.

Outreach was conducted at two statewide conferences 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. The conferences included the Governor's Hurricane Conference in May 2007 and the Southeast Builders Conference in July 2007. Participation in these programs was by way of chairing workshops and delivering presentations focusing on hurricane loss mitigation. An exhibit booth complemented these presentations with IHRC staff present 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. In December 2006 the IHRC hosted the LMS meeting at Florida International University. Approximately 100 participants including community leaders, researchers, policy makers, and industry leaders discussed the mitigation strategies implemented in Miami-Dade County.

The IHRC hosted a structural mitigation expo in cooperation with the Miami Children's Museum and the National Hurricane Center on June 15, 2007. Children between the ages of 3 and 12 learned about hurricane structure and prediction as well as how to prepare and mitigate their homes before hurricane landfall. In addition the IHRC made several presentations throughout the year to K-12 classrooms in Miami-Dade County discussing on-going hurricane research.

IHRC Project Research Team

The 2006-2007 research team was comprised as follows:

Principal Investigator:	Stephen Leatherman	FIU/IHRC
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