Composite Structural Insulated Panels (CSIPs) for Hazards Resistant Structures (Grant # 0825938)

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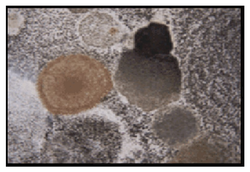
Abstract

Extreme windstorms are frequent and destructive natural hazards in the United States. Each wind disaster proves that traditional wood houses are too fragile to withstand high air pressures. The proposed Composite Structural Insulated Panels (CSIPs) are made of a low-cost, thermoplastic orthotropic glass/poly-propylene (glass-PP) laminate as the face sheet and expanded polystyrene (EPS) foam as the core, with a high face sheet/core moduli ratio. In order to evaluate the wind-resistance of CSIPs, panels with cores of 16 kg/m^3 (1 PCF) and 48 kg/m^3 (3 PCF) density were tested at the University of Florida. Stepwise and dynamic simulated wind pressure was generated by the High Airflow Pressure Loading Actuator. The connections of the CSIPs were 2"×6" lumbers as used in traditional constructions. Top and bottom lumbers were fixed to steel plates with bolts. In stepwise windstorm tests, step-by-step pressure was applied to CSIPs; the highest pressure was equivalent to a wind speed of 124.44 m/s (280 mph). The CSIPs wall system demonstrated superior capacity except local debonding between the face sheet and core; there were connection failures at lumbers in all but one sample. In dynamic windstorm tests, cyclic pressure was used to simulate actual exposure. Only one sample failed at the lumber connection, and there were minor cracks in the lumber connections and local debondings in three of the eight samples. The intact condition of all face sheets and cores after tests indicate the excellent wind-resistance of CSIPs for structural wall applications. Corresponding finite element modeling was developed and initially validated, in a dynamic windstorm test, within the first second for the 1 PCF core density CSIP. The modeling was further investigated with longer durations of exposure. The results were compared, and modifications were projected for future modeling to improve the precision.

Problems of Traditional Construction

Degradation due to Flood

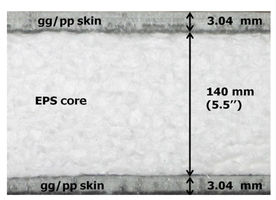
Failure due to Windstorm



Mold Buildups

Poor Impact Resistance

Proposed CSIPs



- Made of expanded polystyrene foam (EPS) as a core which is sandwiched between low cost thermoplastic glass/polypropylene (glass-PP) laminate as face sheets using a thermoplastic spray adhesive.

Advantages:

- Multifunctional Panels (structural and non-structural elements, i.e., floor, wall, roof, pedestrian deck, and lintel panels): Provide insulation properties against heat, sound, and vibrations, in addition to providing strength much higher than traditional constructions
- Light-weight panels requires less labor and time to construct a house, compared to traditional construction

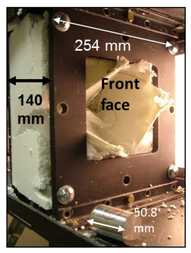
Manufacturing

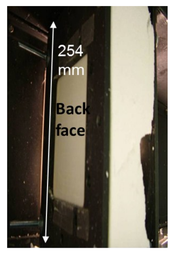
Spraying the hot-melt thermoplastic adhesive on the face sheets

Placing foam core on the sprayed face sheets and applying dead weight to stacking panels

Previous Full-scale Lab Tests

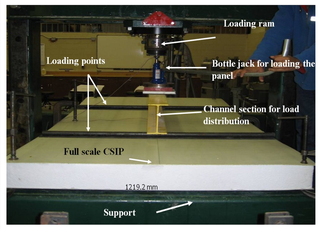
Impact Test

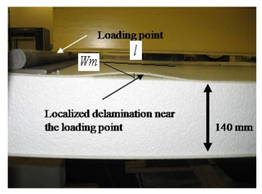




Damaged outside (left) and intact inside (right) subject to FEMA standard impact load

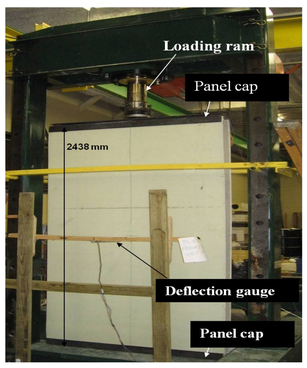
Full-scale Floor Flexural Test

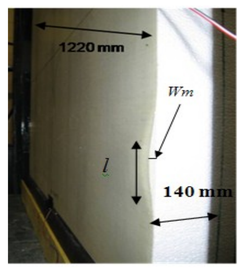




Full-scale floor test showing significant over-capacity against design load (left) and localized debonding failure mode (right)

Full-scale Wall Buckling Test



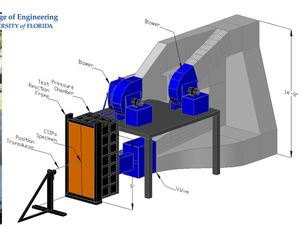


Full-scale wall test demonstrating higher load capacity over design load (left) and localized debonding failure mode (right)

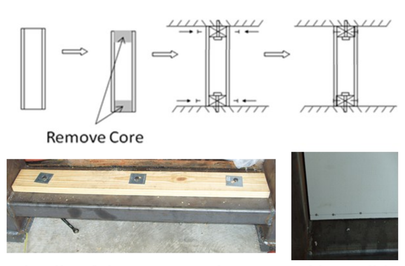
Flood Test

Full-scale flood test showing low wicking and moisture absorption compared to wood (left), and pull-out failure test following the flood test (right)

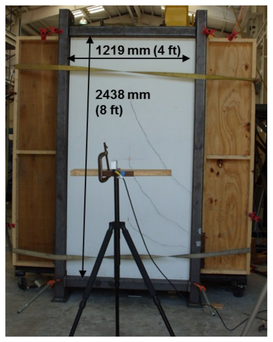
Simulated Windstorm Test



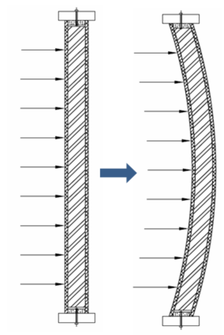
High Airflow Pressure Load Actuator (HAPLA) for windstorm test



Connections details of the test samples as used in traditional wood construction



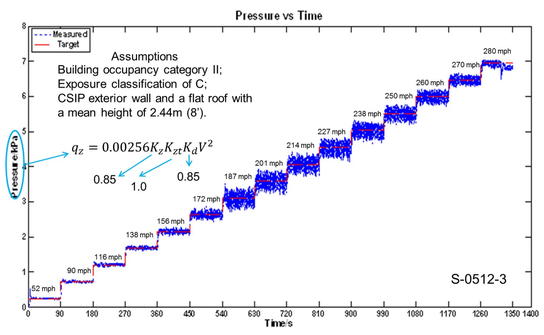
Test setup

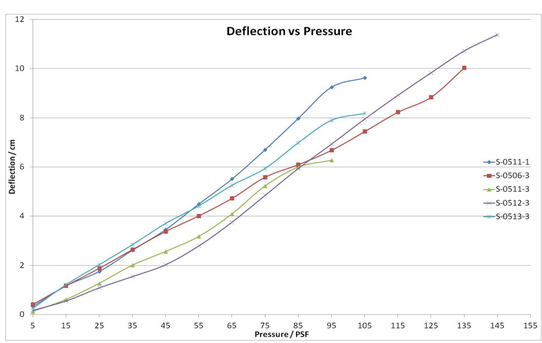


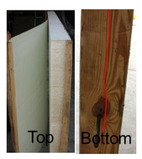
CSIP's behavior under simulated wind pressure from HAPLA

Stepwise Windstorm Test

Test Type	Density	Panel #	Test Date
Stepwise Windstorm Test	16.0Kg/m^3 (1 PCF)	S-0511-1	05/11/11
	48.0Kg/m^3 (3 PCF)	S-0506-3	05/06/11
		S-0511-3	05/11/11
		S-0512-3	05/12/11
		S-0513-3	05/13/11





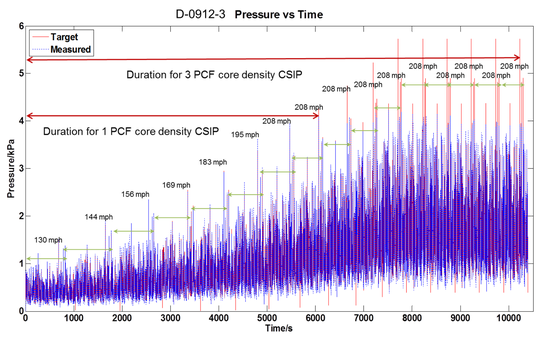


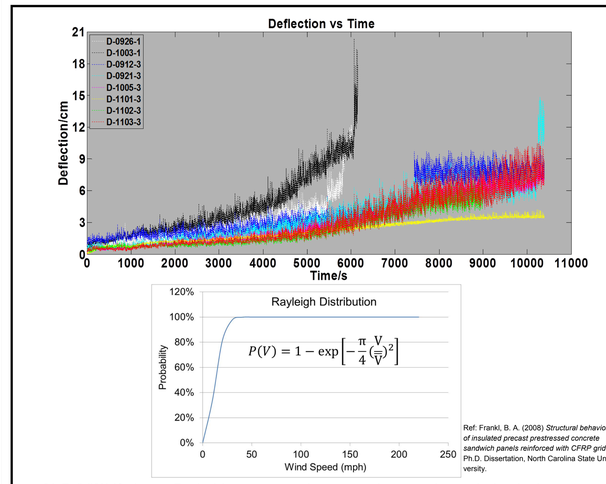
S-0506-3

- Face sheets and cores were intact after tests, no global failure was observed, except some cracking at connections and local debonding between face sheets and core.

Dynamic Windstorm Test

Test Type	Density	Panel #	Test Date
Dynamic Windstorm Test	16.0Kg/m^3 (1 PCF)	D-0926-1	09/26/11
		D-1003-1	10/03/11
	48.0Kg/m^3 (3 PCF)	D-0912-3	09/12/11
		D-0921-3	09/21/11
		D-1025-3	10/25/11
		D-1101-3	11/01/11
		D-1102-3	11/02/11
		D-1103-3	11/03/11



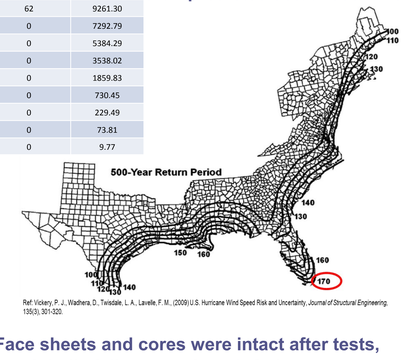


Ref: Frankl, B. A. (2008) *Structural behavior of insulated precast prestressed concrete sandwich panels reinforced with CFRP grid.* Ph.D. Dissertation, North Carolina State University.

[1-P (V)]*Lifetime = Probable exposure time at or above a given wind velocity

D-0912-3 Percent of 170 mph Design Wind Speed	Given Wind Speed / mph	Predicted Probable Exposure Time / s	Actual Exposure Time in Test / s
35%	60	4523	9948.69
40%	68	62	9261.30
50%	85	0	7292.79
60%	102	0	5384.29
70%	119	0	3538.02
80%	136	0	1859.83
90%	153	0	730.45
100%	170	0	229.49
110%	187	0	73.81
122%	208	0	9.77

Through probability calculation, the dynamic test was proven more conservative and rigorous than predicted actual scenario.



Ref: Vickery, P. J., Wadhera, D., Twisdale, L. A., Lavelle, F. M., (2009) U.S. Hurricane Wind Speed Risk and Uncertainty, Journal of Structural Engineering, 135(3), 301-320.

D-1102-3

- Face sheets and cores were intact after tests, no globally failure was found. Only one connection cracking and three local debondings between face sheets and core were observed.

Finite Element Modeling (LS-DYNA)

4-node Shell & MAT054 for face sheet;
8-node Solid & MAT003, MAT 063 for core;
CONTACT TIED SURFACE TO SURFACE;
Element size of 100 mm with 1128 elements;
Explicit solver.

1 PCF core density CSIPs FE modeling with MAT003 and MAT063 as core material.

- MAT 003 gave a almost matched but noisy curve. MAT063 gave a neat but larger values. Additional mechanical properties should be included to improve the FE modeling.

Conclusions

The Composite Structural Insulated Panels (CSIPs) was developed and evaluated in this project. Previous laboratory tests have proven CSIPs to be excellent structural elements for construction compared to traditional panels. By using the newly-developed HAPLA system, the current research investigated the wind resistance of CSIPs as exterior walls. The results of stepwise and dynamic windstorm tests proved that the full-scale CSIPs are capable of resisting an equivalent wind velocity of more than 200 mph without showing substantial structural damage. The finite element modeling gave similar patterns in deflection plots, and more mechanical properties of CSIPs from future tests were expected to improve the modeling.

Acknowledgment

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