Wind Resistance of Green Roof Systems in Florida –

Developing A Wind Test Protocol

Principal Investigator: David O. Prevatt, Ph.D., P.E. (MA)

Co-Investigators: Glenn A. Acomb, FASLA

Forrest J. Masters, Ph.D., P.E. (FL)

Graduate Research Assistant: Tuan D. Vo, E.I.

Research Assistant: Nick K. Schild

College of Engineering
UNIVERSITY of FLORIDA

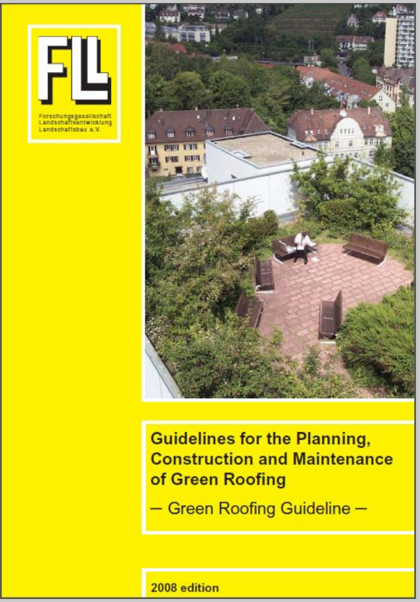
Research Scope and Objectives

- **Task 2:** Investigate the performance of vegetative roof systems appropriate to Florida building for performance in hurricane wind and rain conditions.

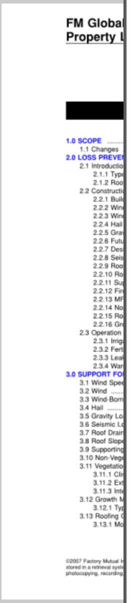
  - (a) Capture and present the most recent research on vegetative roofs in the public domain. Catalogue and compare the vegetative roof systems (in Florida), their (wind) anchorage to the roof structures and installation and design criteria.

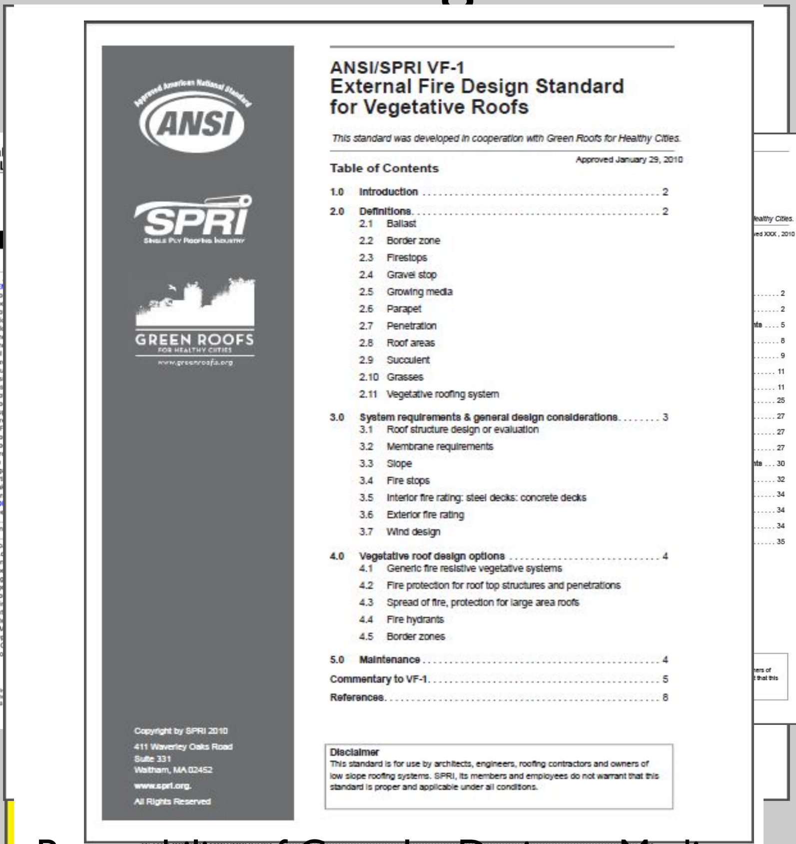
  - Approximately 12 million sq. ft. of green roofing systems in the US.
  - Nearly one-third of these are in southeastern U.S. (including Texas). Less than 2% of US green roofs are installed in Florida.
  - UF Report UF04-11 (September 2011): extensive literature review.
  - No Verification Test Protocol Exists for Wind Uplift Performance

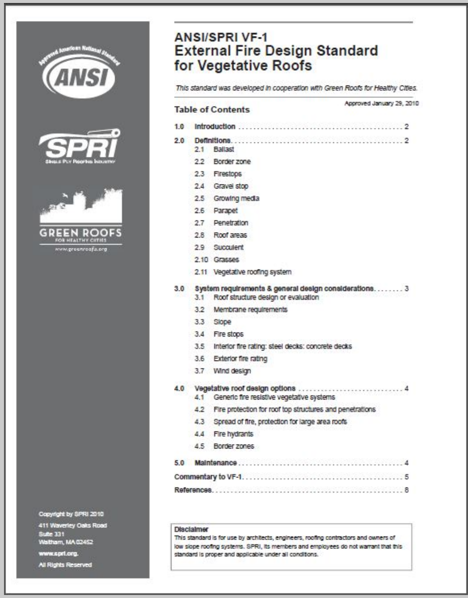
Green Roof Design Guidelines



German FLL







VF-1

ASTM-E2396: Saturated Water Permeability of Granular Drainage Media

ASTM-E2397: Determination of Dead/Live Loads on Green Roof Systems

ASTM-E2398: Water Capture and Media Retention of Geocomposite Drain Layers

ASTM-E2399: Maximum Media Density for Dead Load Analysis

ASTM-E2400: Selection, Installation, and Maintenance of Plants for Green Roof Systems Guide

ANSI/SPRI VF-1: External Fire Design Standard for Vegetative Roofs (SPRI, 2010)

FM Global I-35: Green Roof Systems (Factory Mutual Insurance Company, 2007)

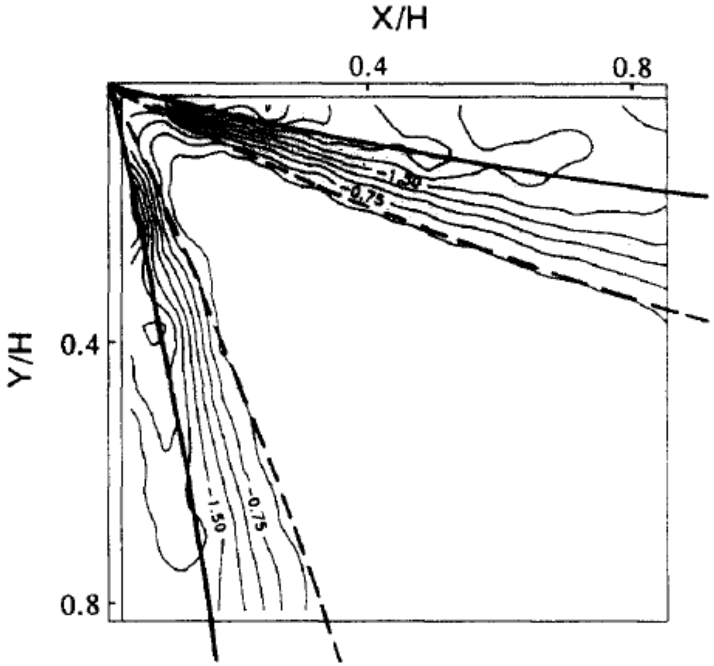
German FLL: Green Roofing Guideline (FLL, 2008)

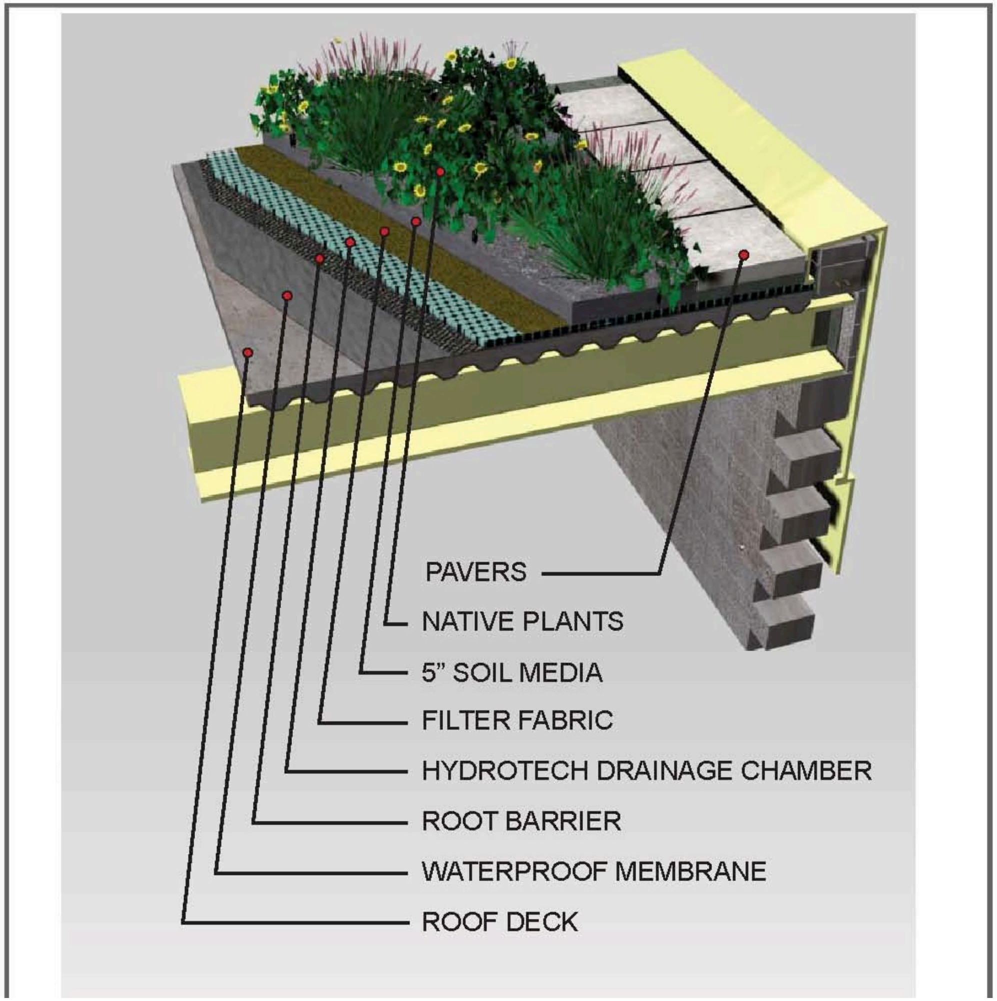
Green Roof Standards/Guidelines

- FLL site condition checklist:
  - Climate and weather-dependent factors
  - Structure-dependent factors
  - Plant-specific factors for design & maintenance (not selection)
- FM Global 1-35: most conservative guide
  - 100 mph limit = restricts green roofs in FL
  - Commercial roofs on metal or concrete decks
- RP-14: Prescriptive wind design guide and tables
  - Unprotected media limit of 5" diameter (influences plant selection)
  - Design tables per ASCE 7-05 wind maps

Recommendation: Florida Green Roof Design Guide should develop from a combination of the FLL, RP-14, VF-1 and FM 1-35.

Wind Load on Green Roof Sytems





Critical wind load:
corner and roof edges

Research Scope and Objectives

- **Phase 2 Tasks:**
  - (b) Conduct wind uplift tests on full scale "Florida-appropriate" green roof systems and develop preliminary understanding of the performance in high winds. Evaluate minimum biomass loss, scouring characteristics, and plant damage for moderate, strong and extreme winds. Determine effect of rain on wind performance. Assess the rate of recovery of vegetation and effect of multiple wind storms.
  - (c) Conduct parametric studies of factors affecting uproot resistance and plant breakage strength of plants used in vegetative roof systems, and scour resistance for green roof systems. Develop a standardized test procedure for evaluating green roofs hurricane wind related performance and submit protocol to ASTM and the Green Roof Council to initiate national consensus standards development.

Experimental Design

- Full-scale wind uplift tests on green roofs systems (6 ft by 6 ft)
- Evaluate three growth media depths: 4 in., 6 in. and 8 in.
- Simulate modular tray and built-in-place green roof systems
- Identify appropriate plants suited to the Florida climate.
- Determine effect of water-soaked growth media on performance
- Develop test methods to evaluate wind uplift capacity of roots

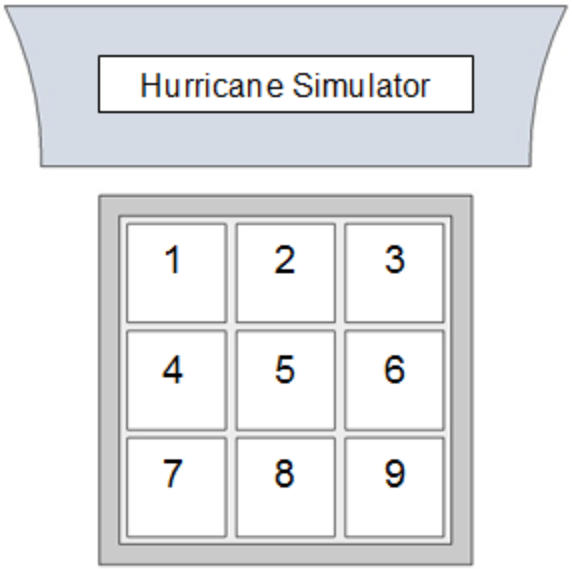
Phase I Test Setup

- 6 tests of modular tray roofs
- 3 tests 4 in. depth, 3 test 8 in. depth
- 9 trays per test, incl. 1 unprotected module
- Wind speeds, 30, 40, 50, 70, 90 120 mph
- 5 minutes each test
- Wind azimuth 90 degrees
- 12 in. high parapet
- 6 plant varieties mixed


4 in. module test at 120 mph
120 mph

Phase I Test Matrix

Phase 1: Modular Tray Green Roof Test Matrix					
Test ID	Wind Testing Date	Establishment Period	Plant Height	Parapet Configuration	Unprotected Module Location
4” – T1	08/18/2011	3 months	Mixed	Encompassing	9
4” – T2	08/18/2011	3 months	Mixed	Encompassing	5
4” – T3	08/18/2011	3 months	Mixed	Encompassing	1
8” – T1	08/18/2011	3 months	Mixed	Encompassing	7
8” – T2	10/20/2011	5 months	Mixed	Encompassing	8
8” – T3	02/16/2011	9 months	Mixed	Back wall removed	8



Module Location Identification

Observation:
Severe scour at corners in unprotected module trays.
8 in. depth growth media trays produce robust plants but severe dieback occurs in dry winter

Examples: Scour at Roof Corner and Edges

Phase 1: Test Trial 1, leeward corner

Phase 2: Test Trial T7, windward corner

Phase 1 Conclusions

- 8” better for plant health than 4” (irrigation needed)
- Protection provided by parapets (but movement of media on roof)
- Dormant woody plants a fire hazard in winter unless fuel removed
- Wind speed under 70 mph not damaging in short term tests
- Limitation of test (simulator produces low turbulence wind flow ~5% TI) which is likely far less damaging than real winds

Phast 2 Test Setup

Phase 2 Test Setup

Phase 2 Test Setup

- 16 Trials; 45 degree wind azimuth; no parapets (conservative)
- 8 tests built-in-place green roof assemblies (normal vs. saturated)
- 8 tests module trays; 4 repeated and 4 6-month old
- Wind speed: 100 mph; held for 10 minutes and 20 minutes
- Trays planted in short plant species and tall species (in 6 month old trays)

Phase 2 Test Matrix

Phase 2: Built-in-Place Green Roof Test Matrix						
Test ID	Plant Date	Wind Testing Date	Establishment Period	Moisture	Plant Height	20 min. test (Y/N ?)
N-S1	04/25/2012	06/12/2012	7 weeks	Normal	Short	No
N-S2	04/25/2012	06/13/2012	7 weeks	Normal	Short	No
N-T1	04/25/2012	06/12/2012	7 weeks	Normal	Tall	No
N-T2	04/25/2012	06/13/2012	7 weeks	Normal	Tall	No
S-S1	04/28/2012	06/13/2012	6.5 weeks	Wet	Short	No
S-S2	04/28/2012	06/13/2012	6.5 weeks	Wet	Short	No
S-T1	04/28/2012	06/19/2012	7.5 weeks	Wet	Tall	Yes*
S-T2	04/28/2012	06/19/2012	7.5 weeks	Wet	Tall	Yes*

Phase 2: Modular Tray Green Roof Test Matrix					
Test ID	Wind Testing Date	Establishment Period	Media Depth	Plant Height	Continued Testing?
T2	06/18/2012	13 months	4”	Mixed	No
T3	06/18/2012	13 months	4”	Mixed	No
T5	06/20/2012	13 months	8”	Mixed	No
T6	06/20/2012	13 months	8”	Mixed	No
T7	06/21/2012	6 months	4”	Tall	Yes
T8	06/20/2012	6 months	4”	Short	No
T10	06/22/2012	6 months	8”	Tall	Yes
T11	06/22/2012	6 months	8”	Short	No

Results: Short versus Tall Plants, & Duration

27.7% -0.8%	20.6% -1.6%	17.8% -0.6%
29.0% -0.6%	26.7% -0.6%	26.1% -1.3%
15.4% -1.0%	28.9% -0.8%	26.9% -0.7%

10 Minute Modular Tray Green Roof Test (T11 – short plant)

Key:
Top: Moisture content
Bottom: Change in weight

19.4% -13.5%	22.0% -2.7%	17.7% -1.2%
14.5% -1.7%	19.3% -2.3%	21.4% +0.2%
17.4% -0.7%	16.0% -0.4%	24.5% -0.9%

20 Minute Modular Tray Green Roof Test (T10 – tall plant)

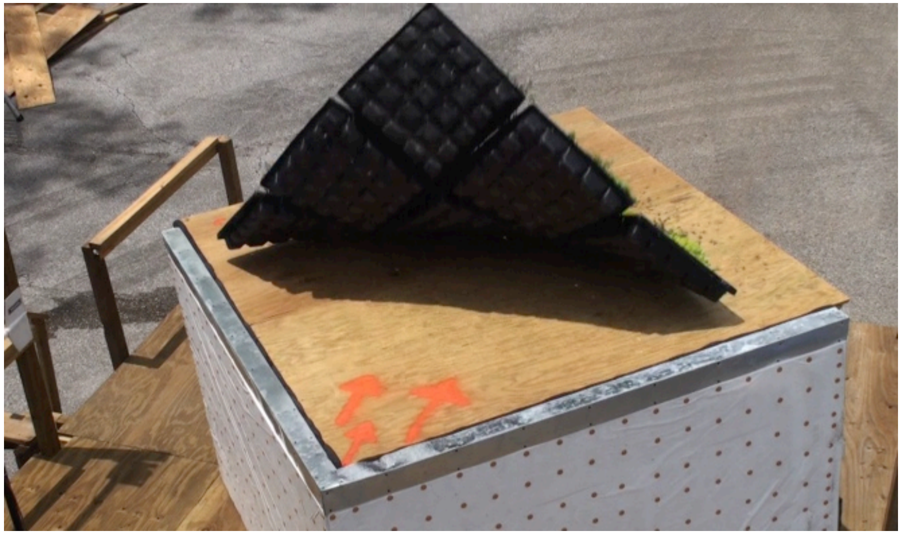
- RECOMMENDATION:

Moisture content was not a major factor

Coverage ratio reduces with time, therefore significant loss in plant coverage in a "normal" hurricane.

Green Roof Anchorage

Case 1: No Internal ties



Case 2: Internal ties provided

RECOMMENDATION:

- Anchorage is required for all green roofs to the structure/substrate
  Unprotected growth media susceptible to scour
- Parapets and sufficient dead load of green roof may minimize failure

Deeper Media Depth = Healthier Plants

4 in. deep module trays

8 in. deep module trays

RECOMMENDATION: Assume 6 in. minimum growth media depth for Florida

1. Decreases heat flux effect on roots
2. Greater dead load mitigates chance of green roof displacement

Plant Height

Tall, Lantana species prior to testing

Short, Portulaca species prior to testing

Short, Portulaca species after testing

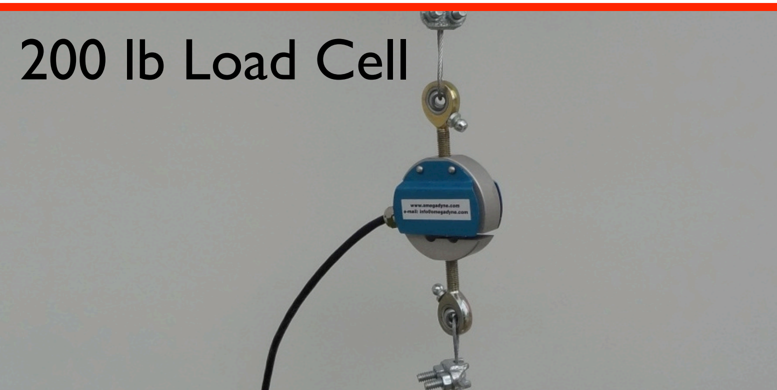
Tall, Lantana species after testing

- RECOMMENDATION: Use low-lying plants (horizontal stem spread) to minimize wind uplift forces.

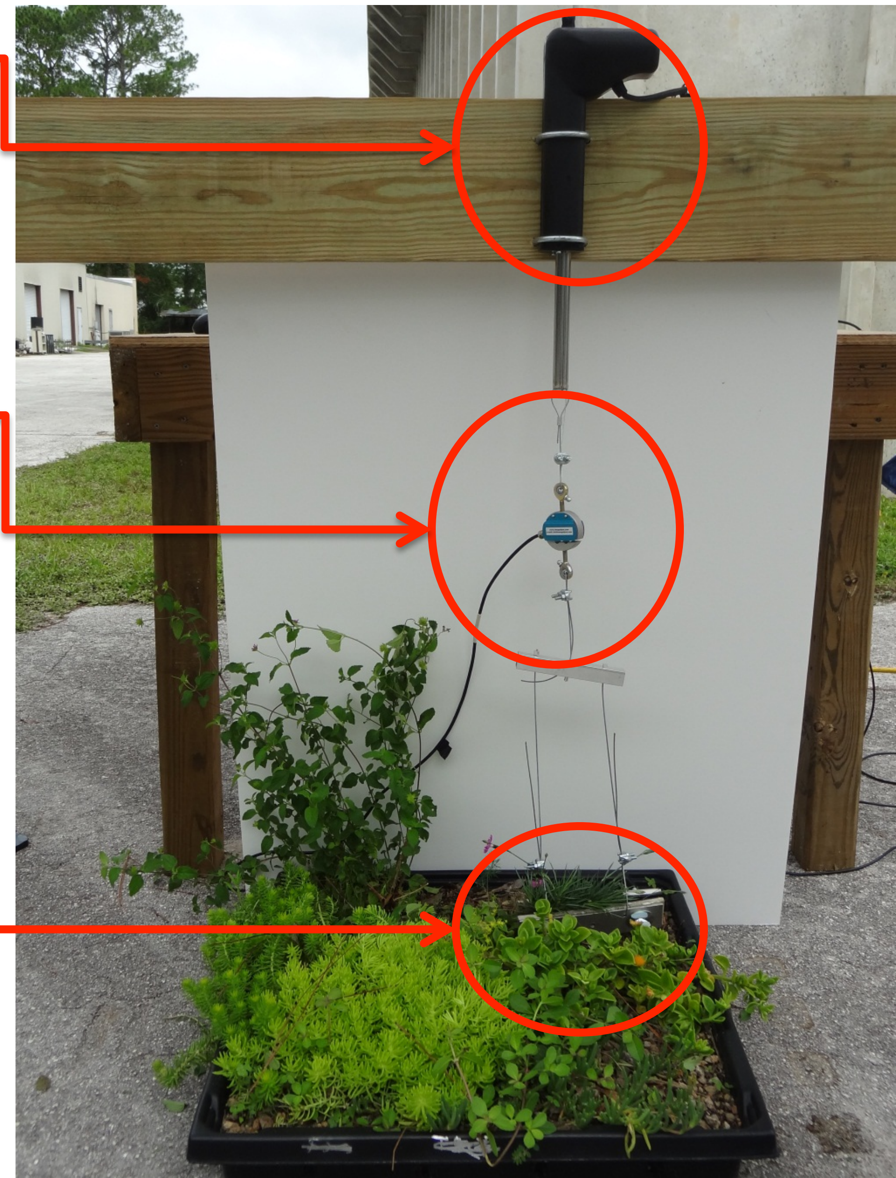
Root Uplift Test Device

6” Linear Actuator

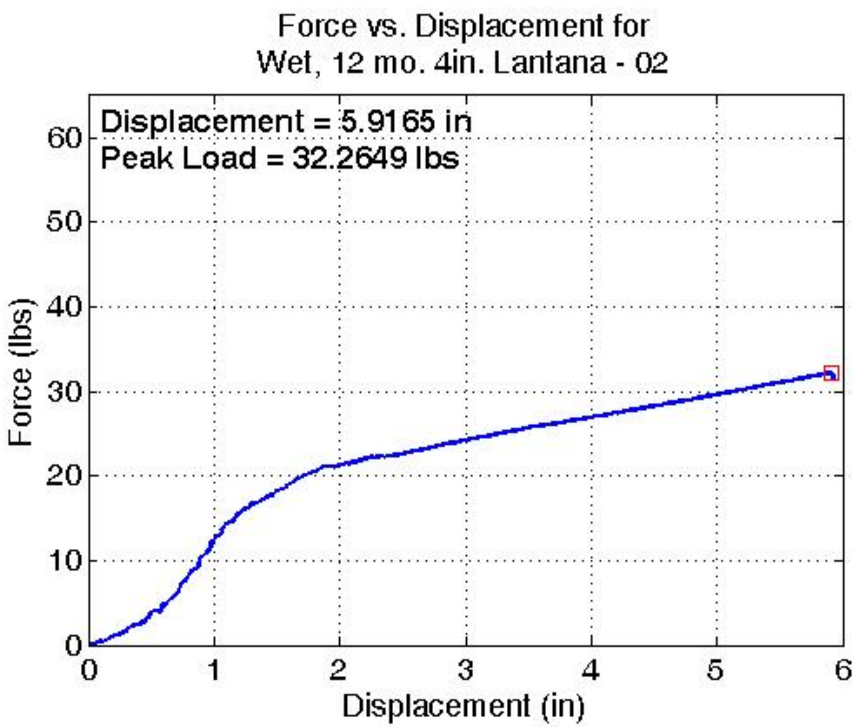
200 lb Load Cell



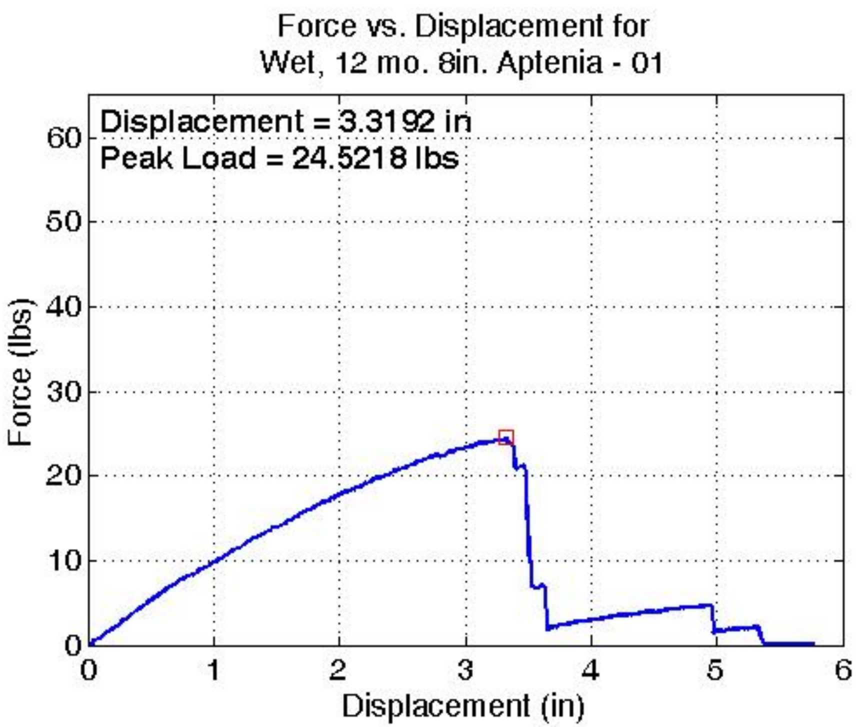
Rubber Padded Steel Plates



Typical Force vs. Displacement Plots



Typical curve denoting 6” upheaval of binded growth media



Typical curve denoting stem/root breakage

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Uproot Resistance

- Root network minimizes scour potential of growth media
- Roots fully bound the media in 6 mo. and 12 mo. modules
- Lantana species showed highest uproot resistance, showing only 1 sign of stem breakage. Delosperma performed the worst.
- Uproot test results suggest that given sufficient establishment, wind damage does not affect uproot resistance of a plant

Green Roof Plant Species for Florida

- Considerations:
  1. Plants must tolerate extreme heat and drought
  2. Plant root system habit and depth must be understood
  3. Plants must be hardy and low-maintenance
  4. Irrigation is needed
  5. Origin of plants should be within the region and grown to match the roof conditions
  6. Plant form and leaf area should limit uplift
  7. Plants should achieve coverage quickly

Plant Selection Performance

- Of the selected plant species, none failed excessively in comparison to each other.
- Taller plant species were more susceptible to bending and root lodging, and resulted in higher amounts of media exposure.
- The originally planted Lantana and Salvia experienced extreme stress after Phase 1, due to sporadic irrigation in the winter months and suffered many losses.
- Succulents perform better in surviving heat and dry extremes, as well as wind desiccation

Summary

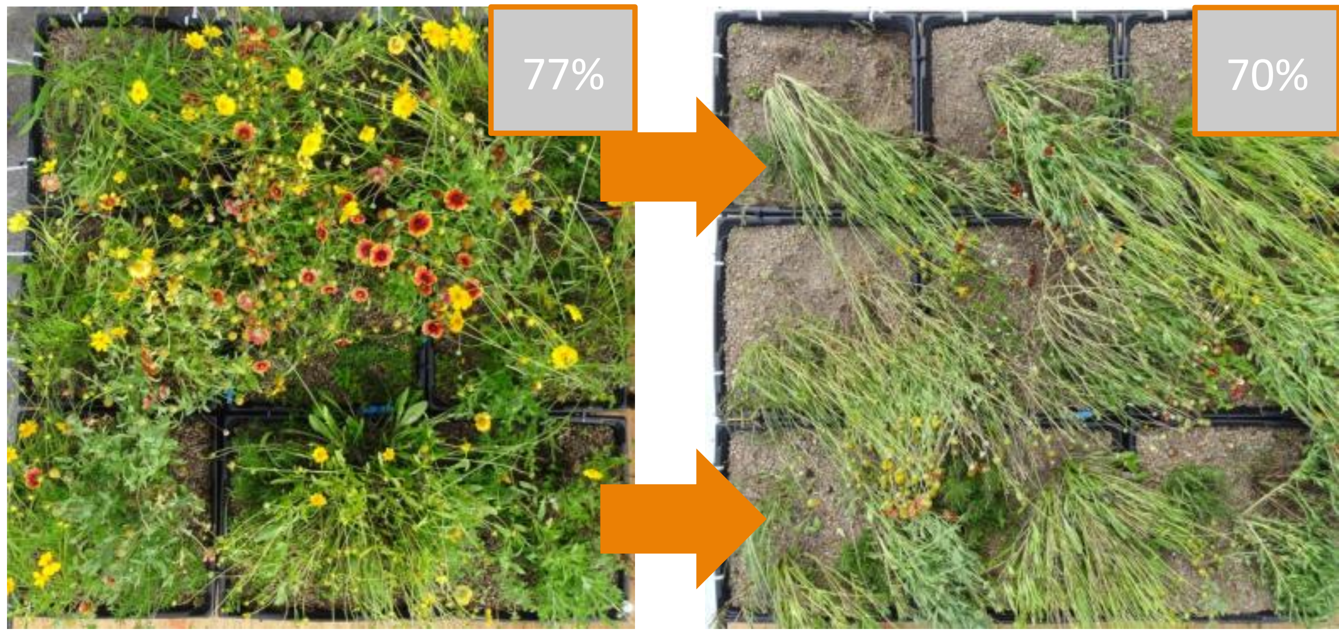
- Major conclusions
  - Avoid using tall plants in significant proportions – reduced wind stresses
  - Vegetation coverage and root networks helpful to reduce scour
  - A minimimum test period of 20 minute recommended (more is better)
  - Root uplift tests useful but need to be calibrated to wind uplift tests.
  - Studies are needed using high turbulence wind flows 9 (15%-25%)
- Future recommendations
  - ASTM E60 Subcommittee: Will review report for inclusion in their work
  - Wind Load on Green Roof at CitiesAlive Conference Chicago 2012
  - Currently 3 scientific papers in preparation on the work

Thank you for Your Attention!

Comments/Questions?

David O. Prevatt
dprev@ufl.edu
352-672-2660

Phase 2: Modular Tray Green Roof Systems



- Measured losses show uniform media loss across the roof surface as opposed to Phase I's redistribution
- Coverage ratio losses were lower in modular trays than built-in-place assemblies
- Modular tray green roofs display localized scour patterns

Phase 2: Built-in-Place Green Roof Systems

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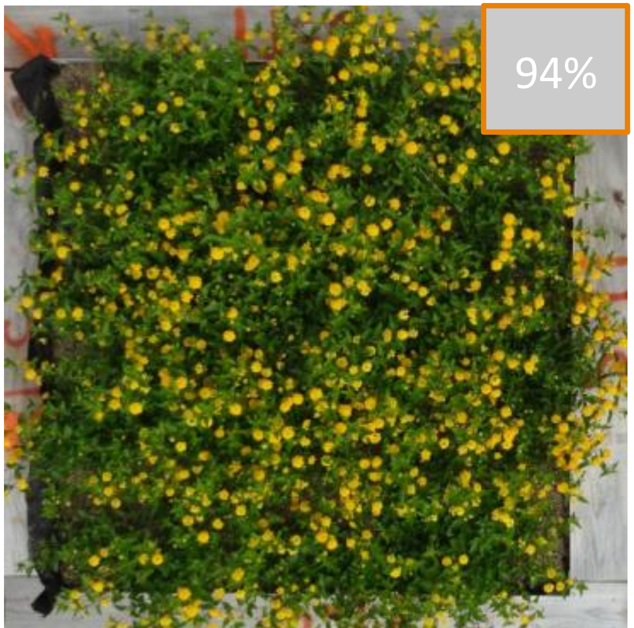

Green Roof Anchorage

- Therefore, through the observed movement in Phase 1 and failures in Phase 2, as well as UCF's documented wind-induced failure, the investigators identified that for adequate system anchorage, it was necessary to implement one (or a combination) of the following options:
  - Install green roof systems with sufficient dead load to resist uplift with proper maintenance and vegetation to provide scour resistance
  - Mechanically attach the green roof system to the roof deck
  - Utilize a parapet of sufficient height to prevent wind flow from reaching the underside of a loosely laid green roof system