

Presented to
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Project summary

The following report describes the methodology followed and summarizes the results of a series of wind tunnel tests to evaluate the resistance to wind uplift of HandyDeck Ipe wood pavers and 3/4" thick structural porcelain pavers manufactured by Kronos Ceramiche using Florida International University's Wall of Wind.

A square-footprint (11 ft. x 11 ft.) base building was used to lay the pavers on a simulated roof deck surface. The roof surface sits at an elevation of 5 ft. above the test section floor. A parapet wall was installed around the roof's perimeter to cover the sides of the paver installation. The height of the parapet wall was adjusted accordingly. The wood pavers tested were made up of a series of IPE wood slats. The setup was consistent with recommended installation on pedestals to allow air circulation and minimize contact with moisture. The monolithic porcelain stoneware pavers were installed on two configurations: on top of adjustable pedestals and with fixed-height on-grade supports.

A series of variables were included on the test program, which include: wind angles, pedestal height and type, parapet wall height, paver layout and the use of locking devices along the perimeter next to parapet walls.

Test method

The testing methodology consisted of "blow off testing" in which direct observations were made of wind speeds of the applied flow and the reaction (if any) from the pavers. Wind induced movement or lifting action was noted and paired with the wind speed at which it occurred. This methodology can be regarded as sufficient to demonstrate the performance of the paver system.

The test plan considered two different types of roof pavers installed on top of pedestals on a flat roof model building (described in the next section) following manufacturer's installation instructions. The testing studied each of the configurations to determine the wind speed at which lift off of one or more pavers occurred. The procedure followed was:

1. The wind speed for each configuration started at a low speed to identify the speed that will produce a reaction from the paver system. For a given wind angle, the wind speed was varied by controlling the throttle of the fan system and was held constant for 1 minute at each wind angle. The wind speed was then increased by 10 mph until a blow off occurs or the maximum wind speed of the Wall of Wind (approximately 150 MPH) is reached.
2. Upon completion of a series of wind speed increments, the pavers that were lifted by the wind were repositioned if not damaged or otherwise replaced with a new paver. The procedure was repeated at least twice

to check the repeatability of the results (wind speed and affected paver. The repetitions were started at two wind speed steps before the blow off occurred on the previous test.

3. The model was rotated to the next wind angle and the procedure repeated. Angle increments of 15 degrees were used as shown on the Figure 1.
4. Observations (and video recording) were made at each wind angle and speed to identify movement or lift off of any of the pavers.
5. The above test procedure was then repeated for each configuration as described on Table 1

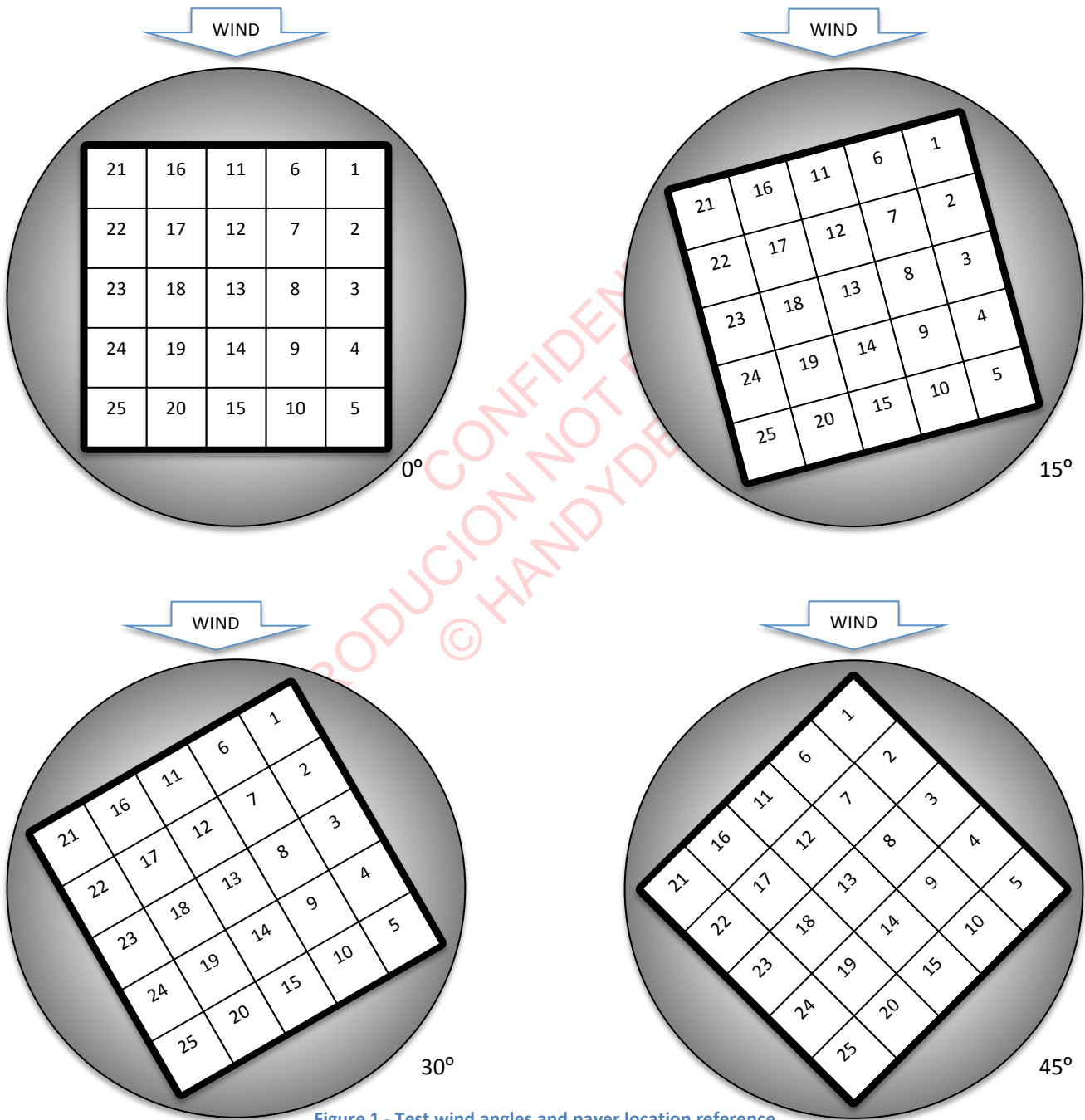


Figure 1 - Test wind angles and paver location reference

Table 1 - Test Configuration Matrix

Paver	Configuration	Pedestal type	Pedestal height (in.)	Parapet height (in.)	Layout	Perimeter locking device	Wind angles
Wood	1	Screw-jack	8	12	Parallel slats	No	0, 15, 30, 45, 90
	2				Basket-weave	No	0, 15, 30, 45
	3				Basket-weave	Yes	45
Porcelain	4	Screw-jack	8	0	-	No	0, 15, 30, 45
	5			12			0, 15, 30, 45
	6	Fixed-height	0.5	0	-	No	30, 45
	7			12			

Instrumentation description

Tests were documented with high definition cameras that recorded video at a two different angles. Both cameras are setup upwind of the structure on opposing sides out of the effect of the wind field and at a height of 14 ft. above the floor. Also free flow wind speed measurements were made using Cobra Probes to calibrate the boundary layer profile and wind speed at each throttle step.



Boundary Layer Profile

The Wall of Wind is a large-scale boundary layer wind tunnel. As such, it uses flow management to give characteristics to the flow that simulate realistic wind conditions. The boundary layer profile simulated for these tests was equivalent to Open terrain. (see Appendix A for more information).

Test specimen description



Two types of pavers were considered in this test program:

Table 2 - Roof paver types used for testing and their physical characteristics

Paver type	Porcelain	IPE wood
		
Nominal dimensions	24 in. (W)	24 in. (W)
	24 in. (L)	24 in. (L)
	3/4 in. (D)	1 11/16 in. (D)
Actual dimensions	23 7/16 in. (W)	23 13/16 in. (W)
	23 7/16 in. (L)	23 13/16 in. (L)
	25/32 in. (D)	1 23/32 in. (D)
Nominal weight	35 lbs	24 lbs
Actual weight	35.75 lbs	24.35 lbs
Porosity (approximate)	0 %	3.7 %

Two different types of pedestals were used:

Table 3 - Pedestal types used for testing and their dimensions

	Fixed Height	Screw-jack
Pedestal type		
Height	0.5 in.	Variable up to 7.25 in.

The base building (Figure 2) had a square footprint of 11 ft. x 11 ft. The roof deck sat at 5 ft. above the turntable floor. Three heights of parapet walls were added to match the required height for each configuration. First wall was 1.5 in. high to be used with the porcelain pavers on top of the fixed-height pedestals. A 9 in. parapet wall was installed along the perimeter of the roof deck for the case with both types of pavers on top of the screw-jack pedestals. A third parapet 12 in. high was installed to provide a 12 in. parapet wall above the pavers for several cases and combinations of type of paver and pedestals.

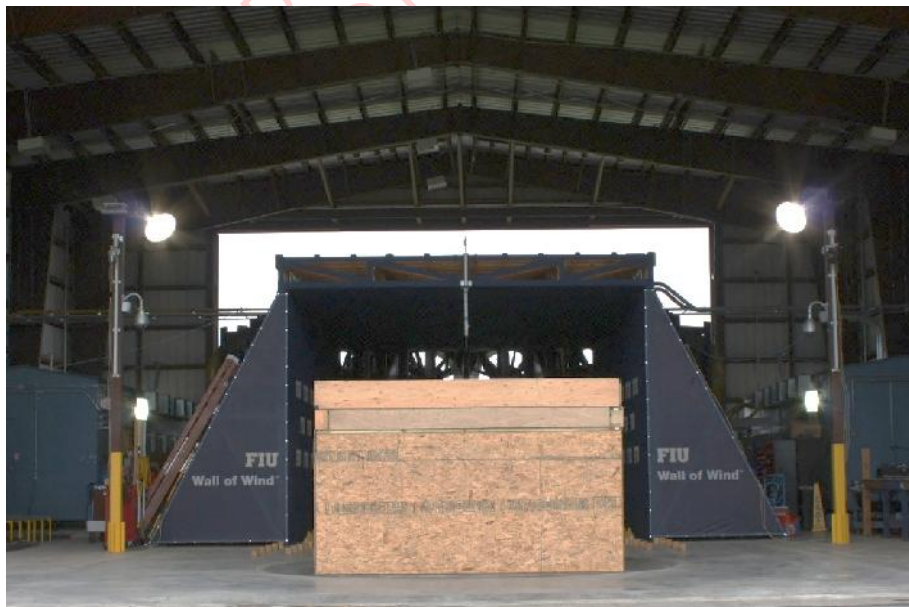


Figure 2 - Base building with 9 in. parapet + 12 in. parapet on top of test section (looking upwind)

Figure 3 shows some of the configurations tested under this test program.



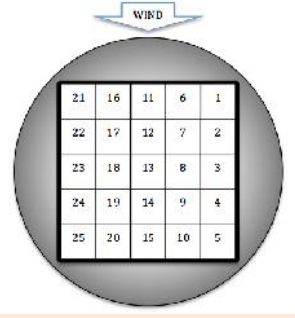
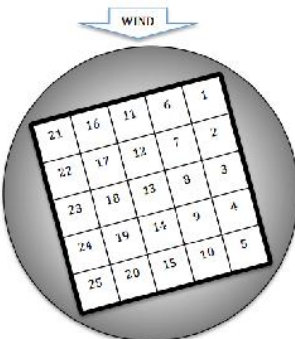
Figure 3 - From top left clockwise: Wood pavers in parallel slats and 12 in. parapet, wood pavers laid out in basket weave and 12. in parapet, porcelain paver with 12 in. parapet and porcelain pavers with 0 in. parapet

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Test Results

The results of the wind-induced effects on both types of pavers with different configurations are summarized on the following tables. "Movement observed" is reported for any paver shaking or moving up and down less than approximately 0.5 in. "Lift-up observed" is reported for any paver moving up more than approximately 0.5 in. "Blow off" stands for any paver carried away by the wind away from its original location. Figures 4 through 17 on Appendix B show a sample of the conditions observed (lift up, missing pedestal, paver blow off) after each test.

IPE wooden slat pavers

Configuration 1 0 degree IPE Wood, Parallel Slats Screw-Jack Pedestal 12 in. parapet	Repetition number	Wind Speed (mph)	Movement observed	Lift-up observed	Blow off
			Paver Number (refer to diagram to the left)		
	0	30	-	-	-
		40	-	-	-
		50	-	-	-
		60	-	-	-
		70	19	-	-
		80	19, 6	-	-
		90	6, 19, 18, 20, 24	-	-
		100	6, 8, 13, 18, 19, 20, 24	-	-
		110	3, 4, 6, 8, 9, 13, 14, 18, 19, 20, 23, 24	-	-
		120	3, 4, 6, 7, 8, 9, 13, 14, 18, 19, 20, 23, 24	-	-
	130	3, 4, 6, 7, 8, 9, 13, 14, 18, 19, 20, 23, 24	8, 13, 18	8, 13	
	1	110	4, 12, 13, 18, 19, 24	-	-
		120	3, 4, 12, 13, 18, 19, 23, 24	3, 4, 8, 12, 13, 18, 23	-
		130	3, 4, 12, 13, 18, 19, 23, 24	3, 4, 8, 12, 13, 18, 23	8
	2	110	4, 8, 13, 19, 24	8, 24	-
120		4, 8, 12, 13, 14, 17, 19, 24	3, 8	-	
130		3, 4, 8, 12, 13, 14, 17, 19, 24	3, 4, 8, 13, 19, 23, 24	8, 13	
Configuration 1 15 degree IPE Wood, Parallel Slats Screw-Jack Pedestal 12 in. parapet	Repetition number	Wind Speed (mph)	Movement observed	Lift-up observed	Blow off
			Paver Number (refer to diagram to the left)		
	0	30	-	-	-
		40	-	-	-
		50	-	-	-
		60	-	-	-
		70	13	-	-
		80	13	-	-
		90	2, 4, 7, 13, 18, 22	-	-
		100	2, 4, 7, 12, 13, 16, 17, 18, 22, 23	2, 7, 12	-
		110	2, 4, 7, 12, 13, 16, 17, 18, 22, 23	1, 2, 6, 7, 12, 17, 22	-
		120	2, 4, 7, 12, 13, 16, 17, 18, 22, 23	12	12
	1	100	2, 7, 12, 13, 17, 18, 22	-	-
		110	2, 3, 6, 7, 8, 11, 12, 16, 17, 18, 19, 22	2, 6, 7, 11, 12, 17, 22	-
		120	2, 3, 6, 7, 8, 11, 12, 16, 17, 18, 19, 22	2, 12	7, 12
	2	100	2, 7, 12, 17, 18, 21, 22	2, 7, 21	-
		110	1, 2, 7, 12, 16, 17, 18, 21, 22, 23	1, 2, 7, 12, 16, 17, 21	2
120		1, 2, 7, 12, 16, 17, 18, 21, 22, 23	1, 2, 7, 12, 16, 17, 21	2, 7	

Configuration 1 30 degree IPE Wood, Parallel Slats Screw-Jack Pedestal 12 in. parapet	Repetition number	Wind Speed (mph)	Movement observed	Lift-up observed	Blow off
			Paver Number (refer to diagram to the left)		
	0	30	-	-	-
		40	-	-	-
		50	-	-	-
		60	-	-	-
		70	21	-	-
		80	2, 6, 7, 11, 16, 21	-	-
		90	1, 2, 6, 7, 11, 12, 16, 21	2, 6, 7, 11, 12, 16, 21	-
	100	1, 2, 6, 7, 11, 12, 16, 21	2, 6, 7, 11, 12, 16, 21	2	
	1	80	2, 7, 21	21	-
		90	1, 2, 6, 7, 11, 12, 16, 21	2, 6, 7, 12, 21	-
		100	1, 2, 6, 7, 11, 12, 16, 18, 21	2, 6, 7, 11, 12, 21	7
	2	80	6, 12, 21	-	-
		90	6, 7, 11, 12, 16, 17, 18, 21	6, 7, 11, 12, 16, 21	-
		100	6, 7, 11, 12, 16, 17, 18, 21	2, 6, 7, 11, 12, 16, 21	2

Configuration 1 45 degree IPE Wood, Parallel Slats Screw-Jack Pedestal 12 in. parapet	Repetition number	Wind Speed (mph)	Movement observed	Lift-up observed	Blow off
			Paver Number (refer to diagram to the left)		
	0	30	-	-	-
		40	-	-	-
		50	-	-	-
		60	-	-	-
		70	21	-	-
		80	2, 6, 21	-	-
		90	1, 2, 3, 6, 16	1, 2, 6	-
	100	1, 2, 3, 6, 16	1, 2, 6	2, 6	
	1	80	2, 6, 21	-	-
		90	1, 2, 6, 21	2	2
		100	-	-	-
	2	80	2, 6, 21	2	-
		90	1, 2, 6, 21	1, 2, 6	1
		100	-	-	-

Configuration 1 90 degree IPE Wood, Parallel Slats Screw-Jack Pedestal 12 in. parapet	Repetition number	Wind Speed (mph)	Movement observed	Lift-up observed	Blow off	
			Paver Number (refer to diagram to the left)			
	0	30	-	-	-	
		40	-	-	-	
		50	-	-	-	
		60	-	-	-	
		70	-	-	-	
		80	-	-	-	
		90	-	-	-	
		100	8, 11, 12, 13, 14, 15,	2, 7, 12	-	
		110	2, 4, 7, 12, 13, 16, 17, 18, 22, 23	1, 2, 6, 7, 12, 17, 22	-	
	1	120	2, 4, 7, 12, 13, 16, 17, 18, 22, 23	2, 6, 7, 8, 10, 11, 12, 13, 14, 15, 16, 17, 22	-	
		130	2, 4, 7, 12, 13, 16, 17, 18, 22, 23	2, 6, 7, 8, 10, 11, 12, 13, 14, 15, 16, 17, 22	13	
		2	110	6, 8, 11, 12, 13	-	-
			120	6, 8, 11, 12, 13	11	-
			130	6, 7, 8, 11, 12, 13, 14, 15, 16, 21	13	13
		2	110	6, 8, 11, 12, 13, 16, 19, 20	12, 13	-
120	6, 8, 11, 12, 13, 16, 19, 20		6, 10, 11, 12, 13, 14, 16, 20	-		
130	6, 8, 11, 12, 13, 16, 19, 20		13	13		

Configuration 2 0 degree IPE Wood, Basket weave Screw-Jack Pedestal 12 in. parapet	Repetition number	Wind Speed (mph)	Movement observed	Lift-up observed	Blow off
			Paver Number (refer to diagram to the left)		
	0	30	-	-	-
		40	-	-	-
		50	-	-	-
		60	-	-	-
		70	-	-	-
		80	-	-	-
		90	-	-	-
		100	4, 12, 13, 19, 20, 23, 24	-	-
		110	3, 4, 12, 13, 18, 19, 20, 23, 24	3, 13, 23	-
		120	2, 3, 4, 7, 8, 11, 12, 13, 17, 18, 19, 20, 23, 24	3, 7, 12, 13, 18, 23	-
	130	2, 3, 4, 7, 8, 11, 12, 13, 18, 19, 20, 23, 24	2, 3, 7, 8, 12, 13, 18, 23	13	
	1	110	3, 4, 8, 13, 18, 23, 24	3, 13, 18, 23	-
		120	3, 4, 8, 13, 18, 23, 24	3, 8, 13, 18, 23, 24	-
		130	3, 4, 8, 12, 13, 17, 18, 19, 23, 24	3, 8, 12, 13, 17, 18, 22, 23, 24	-
		140	2, 3, 4, 7, 8, 12, 13, 17, 18, 19, 22, 23, 24	3, 8, 12, 13, 17, 18, 22, 23, 24	8, 13
2	110	2, 3, 18, 19, 23, 24	2, 13, 18, 23	-	
	120	2, 3, 7, 8, 12, 13, 18, 19, 23	2, 3, 4, 8, 12, 13, 18, 22, 23	-	
	130	2, 3, 7, 8, 12, 13, 18, 19, 23	2, 3, 4, 8, 12, 13, 18, 22, 23	13	

Configuration 2 15 degree IPE Wood, Basket weave Screw-Jack Pedestal 12 in. parapet	Repetition number	Wind Speed (mph)	Movement observed	Lift-up observed	Blow off
			Paver Number (refer to diagram to the left)		
	0	30	-	-	-
		40	-	-	-
		50	-	-	-
		60	-	-	-
		70	17	-	-
		80	17, 22, 24	-	-
		90	2, 7, 16, 17, 18, 19, 21, 22, 24	21	-
		100	2, 7, 13, 17, 18, 19, 21, 22, 24	2, 6, 7, 12, 16, 21, 22	-
		110	2, 7, 13, 17, 18, 19, 21, 22, 24	2, 6, 7, 12, 16, 21, 22	7
		1	90	2, 7, 17, 18, 21, 24	21
	100		2, 7, 17, 18, 21, 24	2, 6, 7, 16, 17, 21, 22	-
	110		2, 6, 7, 17, 18, 21, 24	2, 6, 7, 16, 17, 21, 22	6
	2	90	2, 3, 7, 12, 17, 19, 21, 22, 24	-	-
		100	2, 3, 7, 12, 17, 18, 21, 22, 23, 24	2, 6, 7, 12, 21, 22	-
		110	2, 3, 7, 12, 17, 18, 21, 22, 23, 24	2, 6, 7, 11, 12, 21, 22	2

Configuration 2 30 degree IPE Wood, Basket weave Screw-Jack Pedestal 12 in. parapet	Repetition number	Wind Speed (mph)	Movement observed	Lift-up observed	Blow off
			Paver Number (refer to diagram to the left)		
	0	30	-	-	-
		40	-	-	-
		50	-	-	-
		60	-	-	-
		70	-	-	-
		80	16, 17, 21	-	-
		90	2, 6, 7, 12, 16, 17, 21	2, 6, 7, 12, 16, 21	-
		100	2, 6, 7, 12, 16, 17, 21	2, 6, 7, 12, 16, 21	6
	1	80	2, 6, 7, 16, 19, 21	-	-
		90	2, 6, 7, 16, 19, 21	2, 6, 7, 12, 16, 21	-
		100	2, 6, 7, 11, 12, 16, 17, 19, 21, 22	2, 6, 7, 12, 16, 21	6
			2, 6, 7, 12, 16, 17, 19, 21	2, 6, 7, 11, 12, 16, 21	-
2	80	6, 16, 17, 21	21	-	
	90	2, 6, 7, 12, 16, 17, 19, 21	2, 6, 7, 11, 12, 16, 21	-	
	100	2, 6, 7, 12, 16, 17, 19, 21	2, 6, 7, 11, 12, 16, 21	6	

Configuration 2 45 degree IPE Wood, Basket weave Screw-Jack Pedestal 12 in. parapet	Repetition number	Wind Speed (mph)	Movement observed	Lift-up observed	Blow off
			Paver Number (refer to diagram to the left)		
	0	30	-	-	-
		40	-	-	-
		50	-	-	-
		60	-	-	-
		70	-	-	-
		80	2, 6	2, 6	-
		90	1, 2, 6	1, 2, 6	1
	1	70	6	-	-
		80	1, 2, 6	1, 2, 6	-
		90	1, 2, 6	1, 2, 6	1
	2	70	-	-	-
		80	1, 2, 6	1, 2, 6	-
90	1, 2, 6	1, 2, 6	1		

Configuration 3 45 degree IPE Wood, Basket weave Screw-Jack Pedestal 12 in. parapet Perimeter locks	Repetition number	Wind Speed (mph)	Movement observed	Lift-up observed	Blow off
			Paver Number (refer to diagram to the left)		
	0	60	-	-	-
		70	-	-	-
		80	2, 6	-	-
		90	2, 3, 6, 11	2, 6	-
		100	2, 3, 4, 6, 11, 16	2, 6	-
		110	2, 3, 4, 6, 7, 11, 16, 21	2, 6, 7	-
		120	2, 3, 4, 6, 7, 11, 16, 21	2, 6, 7, 12	12
	1	80	2, 3, 6, 11	-	-
		90	2, 3, 6, 11	2, 6	-
		100	2, 3, 4, 6, 11, 16	2, 6	-
		110	2, 3, 4, 6, 7, 11, 12, 16, 21	2, 6, 7	-
		120	2, 3, 4, 6, 7, 11, 12, 16, 21	2, 6, 7, 11	6, 7, 11

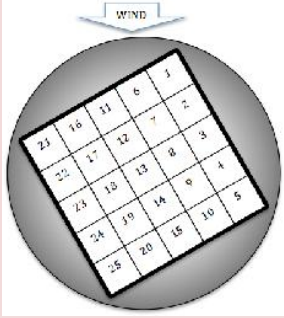
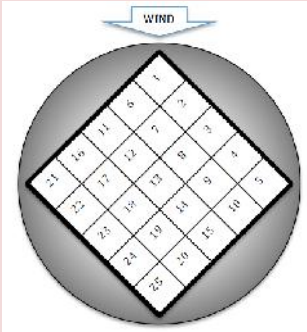
Porcelain Pavers

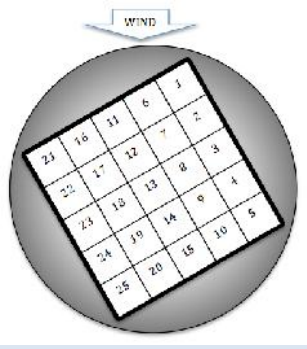
Configuration 4 0 degree Porcelain Screw-Jack Pedestal 0 in. parapet	Repetition number	Wind Speed (mph)	Movement observed	Lift-up observed	Blow off		
			Paver Number (refer to diagram to the left)				
	0	60	-	-	-		
		70	-	-	-		
		80	-	-	-		
		90	1, 6, 11, 16, 21	1, 6, 11, 16, 21	-		
		100	1, 6, 11, 16, 21, 23	1, 6, 11, 16, 21	-		
		110	1, 6, 11, 16, 21, 23	1, 6, 11, 16, 21	21		
	1	80	6, 11, 16, 21	-	-		
		90	1, 6, 11, 16, 21	1, 6, 11, 16, 21	-		
		100	1, 6, 11, 12, 16, 17, 21	1, 6, 11, 16, 21	-		
		110	1, 6, 11, 12, 16, 17, 21	1, 6, 11, 16, 21	1, 6		
Configuration 4 15 degree Porcelain Screw-Jack Pedestal 0 in. parapet	Repetition number	Wind Speed (mph)	Movement observed	Lift-up observed	Blow off		
			Paver Number (refer to diagram to the left)				
	0	60	-	-	-		
		70	-	-	-		
		80	1, 6, 17	1	-		
		90	1, 6, 17	1	1		
	1	70	-	-	-		
		80	1, 6, 11, 16, 17	1, 6	-		
		90	1, 6, 11, 17	1, 6	1		
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		Configuration 4 30 degree Porcelain Screw-Jack Pedestal 0 in. parapet	Repetition number	Wind Speed (mph)	Movement observed	Lift-up observed	Blow off
					Paver Number (refer to diagram to the left)		
	0	60	-	-	-		
		70	-	-	-		
		80	6	6	-		
		90	6	6	6		
	1	70	-	-	6	-	
		80	6	6	-		
		90	6	6	6		

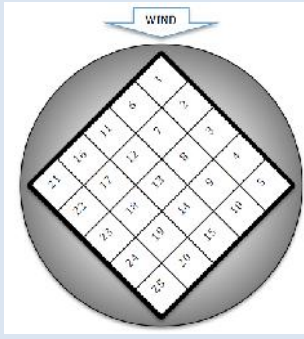
Configuration 4 45 degree Porcelain Screw-Jack Pedestal 0 in. parapet	Repetition number	Wind Speed (mph)	Movement observed	Lift-up observed	Blow off
			Paver Number (refer to diagram to the left)		
	0	60	-	-	-
		70	-	-	-
		80	-	-	-
		90	2, 3, 6	2, 3, 6	2
	1	70	-	-	-
		80	-	-	-
		90	2, 3, 6	3, 6	3

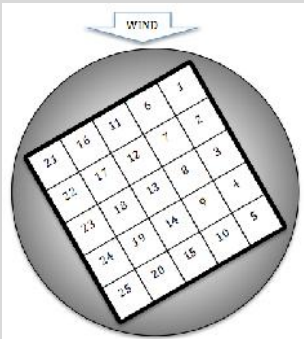
Configuration 5 0 degree Porcelain Screw-Jack Pedestal 12 in. parapet	Repetition number	Wind Speed (mph)	Movement observed	Lift-up observed	Blow off
			Paver Number (refer to diagram to the left)		
	0	70	-	-	-
		80	-	-	-
		90	-	-	-
		100	-	-	-
		110	11, 17, 23, 24	-	-
		120	3, 4, 11, 13, 17, 18, 23, 24	-	-
		130	3, 4, 8, 9, 13, 14, 18, 19, 23, 24	3, 13, 18, 23, 24	-
		140	3, 4, 7, 8, 9, 12, 13, 14, 18, 19, 23, 24	3, 4, 7, 8, 12, 13, 18, 23	13
*Note: back parapet sheeting broke at 140 mph, test was stopped and parapet was fixed and this wind speed step completed.					

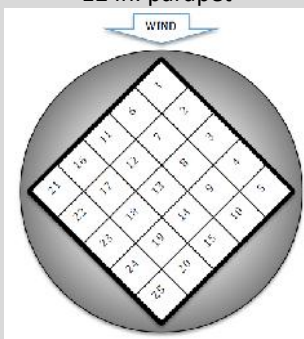
Configuration 5 15 degree Porcelain Screw-Jack Pedestal 12 in. parapet	Repetition number	Wind Speed (mph)	Movement observed	Lift-up observed	Blow off
			Paver Number (refer to diagram to the left)		
	0	70	-	-	-
		80	-	-	-
		90	-	-	-
		100	6, 9, 11, 17, 22	22	-
		110	1, 2, 4, 6, 7, 9, 11, 12, 13, 16, 17, 18, 21, 22	1, 2, 6, 7, 12, 18, 21	-
		120	1, 2, 4, 6, 7, 9, 11, 13, 16, 17, 18, 21, 22	1, 2, 6, 7, 12, 18, 21	7

Configuration 5 30 degree Porcelain Screw-Jack Pedestal 12 in. parapet 	Repetition number	Wind Speed (mph)	Movement observed	Lift-up observed	Blow off
			Paver Number (refer to diagram to the left)		
	0	70	-	-	-
		80	7	-	-
		90	6, 7, 8, 12	-	-
		100	1, 2, 6, 7, 8, 11, 12, 21	1, 2, 6, 7, 11	-
		110	1, 2, 6, 7, 8, 11, 12, 21	1, 6	6
Configuration 5 45 degree Porcelain Screw-Jack Pedestal 12 in. parapet 	Repetition number	Wind Speed (mph)	Movement observed	Lift-up observed	Blow off
			Paver Number (refer to diagram to the left)		
	0	70	-	-	-
		80	-	-	-
		90	1, 2, 6	1, 2, 6	-
		100	1, 2, 6	1, 2, 6	-
		110	1, 2, 6	1, 2, 6	1
1		90	1, 2, 6	-	-
		100	1, 2, 6	1, 6	1
		110	-	-	-

Configuration 6 30 degree Porcelain Fixed-height Pedestal 0 in. parapet 	Repetition number	Wind Speed (mph)	Movement observed	Lift-up observed	Blow off
			Paver Number (refer to diagram to the left)		
	0	80	-	-	-
		90	6	6	-
		100	6, 11	6, 11	-
		110	6, 11, 16	6, 11	-
		120	6, 11, 16, 21	6, 11, 16, 21	-
		130	6, 11, 16, 17, 21	11, 16	11, 16

Configuration 6 45 degree Porcelain Fixed-height Pedestal 0 in. parapet	Repetition number	Wind Speed (mph)	Movement observed	Lift-up observed	Blow off
			Paver Number (refer to diagram to the left)		
	0	70	-	-	-
		80	-	-	-
		90	-	-	-
		100	3, 11, 16	3	-
		110	3, 4, 11, 16	3, 11	-
		120	3, 4, 5, 6, 11, 16	3, 4, 6, 11, 16	-
		130	2, 3, 4, 5, 6, 11, 16	3, 4, 6, 11, 16	3, 4, 5

Configuration 7 30 degree Porcelain Fixed-height Pedestal 12 in. parapet	Repetition number	Wind Speed (mph)	Movement observed	Lift-up observed	Blow off
			Paver Number (refer to diagram to the left)		
	0	60	-	-	-
		70	12	-	-
		80	12	-	-
		90	12, 21	-	-
		100	12, 21	21	-
		110	6, 11, 12, 16, 21	6, 21	-
		120	1, 6, 11, 12, 16, 21	1, 6, 11	-
		130	1, 6, 11, 12, 16, 17, 21, 22	6, 11, 12, 16, 17, 21, 22	6, 11, 12, 17

Configuration 7 45 degree Porcelain Fixed-height Pedestal 12 in. parapet	Repetition number	Wind Speed (mph)	Movement observed	Lift-up observed	Blow off
			Paver Number (refer to diagram to the left)		
	0	60	-	-	-
		70	12	-	-
		80	12, 20	-	-
		90	7, 12, 17, 20	-	-
		100	7, 12, 17, 20	-	-
		110	7, 12, 17, 20, 21	-	-
		120	1, 6, 7, 12, 16, 17, 20, 21	2, 6	-
		130	1, 2, 3, 4, 6, 7, 11, 12, 17, 20, 21	1, 2, 3, 6, 7, 11, 16	-
		140	1, 2, 3, 4, 6, 7, 11, 12, 17, 20, 21	1, 6, 7, 11, 16	6, 11, 16
		150	1, 2, 3, 4, 6, 7, 11, 12, 17, 20, 21	1, 6, 7, 11, 16, 21	21

Observations

Pedestals

1. Once movement (shaking) is observed on the pavers weight is shifted on the pedestals (fixed height and/or screw jack) allowing the pedestals to shift its original location as the weight. Neither type of pedestals is fixed to the roof and relies on the paver weight on it and friction between the roof and pedestal to maintain its intended position.
2. It was also observed that when pedestals move and pavers were lifted, some of the fixed height pedestals were blown off by the wind and also the cap plate on some of the screw jack pedestals were blown off.
3. Pavers that shake and bounce with the wind may break the spacer tabs on the pedestal's cap. This was a common observation throughout the tests. Even if the paver is not blown off, paver will need to be reset and possibly caps with broken tabs replaced to maintain a consistent gap.
4. It was observed that the height of the cavity under the pavers, the type of pedestal, the porosity of the paver or a combination of the above had an effect on the wind speed at which lift-up and/or blow off of pavers was seen. The porcelain pavers were tested with both the screw jack and fixed-height pedestals so comparison can be made. With the fixed-height pedestals and 12-in parapet, the wind speed needed to blow off the pavers off the roof was in the order of 30-40 mph higher when compared to the case with screw-jack pedestals. For the case with the 0-inch parapet an increase in wind speed of approximately 40 mph was needed for pavers to blow off with the fixed-height pedestals compared to the screw-jack type.

Parallel slats and basket weave for IPE wooden pavers

5. It could not be determined if there was a significant difference on the resistance to wind up lift on pavers laid out with slats parallel to each other when the wind was parallel to the slats or perpendicular to them.
6. It was observed that movement and lift up of pavers occurred at a lower wind speed (approximately 10 mph earlier) for the basket weave case compared to the parallel slats configuration. The wind speed at which the pavers were blown off was also 10 mph lower for most wind angles.

Parapet wall

7. It was observed that when the 12 in parapet wall was installed, the wind speed required to blow off the pavers was higher than for the cases without the wall (this was only evaluated with the porcelain pavers).
8. It appears that the height of the parapet wall as tested in this configuration and roof deck size provides the pavers some sheltering from the wind. When the pavers were blown off, it is worth noticing that the paver moved into the direction of the oncoming wind. This suggests recirculation of the flow within the roof deck.

Wind angle

9. It was noted that the wind angle at which movement, lift up or blow off was observed the earliest was 45 degrees.
10. Also at 0 degrees, the wind speed necessary to blow off a paver was higher than at other angles, but the number of pavers moving or lifting up and down was also higher.
11. In some cases with the 12 in. parapet wall and at 15 and 30 degrees, some pavers can be seen hovering approximately 0.5-0.75 inches above the roof deck.

Repeatability

12. It was determined that the repeatability of the tests was fairly consistent among the different iterations made. In most cases the same paver would be blown off at the same wind speed. In the cases when it did not, it was one of the pavers next to it, or from the group of pavers that were moving/lifting with the wind.
13. The test plan was adjusted to allow for the maximum number of test cases to be accomplished. The number of repetitions for some cases and the test start wind speed was adjusted after evaluation and comparison of trial runs with similar configurations. This was especially important for the ceramic pavers that once blown away were chipped and in the worst cases shattered.

Perimeter locking device

14. The locking device was added for the case at 45 degrees to hold the perimeter tiles from lifting up. The locking device consisted of a 1 in x 1 in extruded aluminum 90-degree angle bracket screwed. One was installed between every two pavers only at the perimeter pavers next to the parapet wall. The aluminum bracket was screwed into parapet and not to the paver. It was observed that the brackets held down the edges of the pavers closest to the parapet wall but the wind was still able to lift the pavers by the edges on the roof's field. This type of locking device may help if the corners of the pavers are locked together throughout the field.

Wind speed

15. The wind speed recorded before lift-up of pavers was observed was:
 - i. IPE paver with 12-inch parapet: 80 mph
 - ii. Porcelain paver with 0-inch parapet: 80 mph
 - iii. Porcelain paver with 12-inch parapet: 90 mph
16. The maximum wind speed recorded at which pavers blown off was observed:
 - i. IPE paver with 12-in parapet: 130 mph, at 0 degrees
 - ii. Porcelain paver with 0-in parapet: 130 mph, at 45 degrees wind angle and fixed-height pedestal.
 - iii. Porcelain paver with 12-in parapet: 150 mph, at 30 and 45 degrees wind angle and fixed-height pedestal.

Appendix A – Wall of Wind wind characteristics

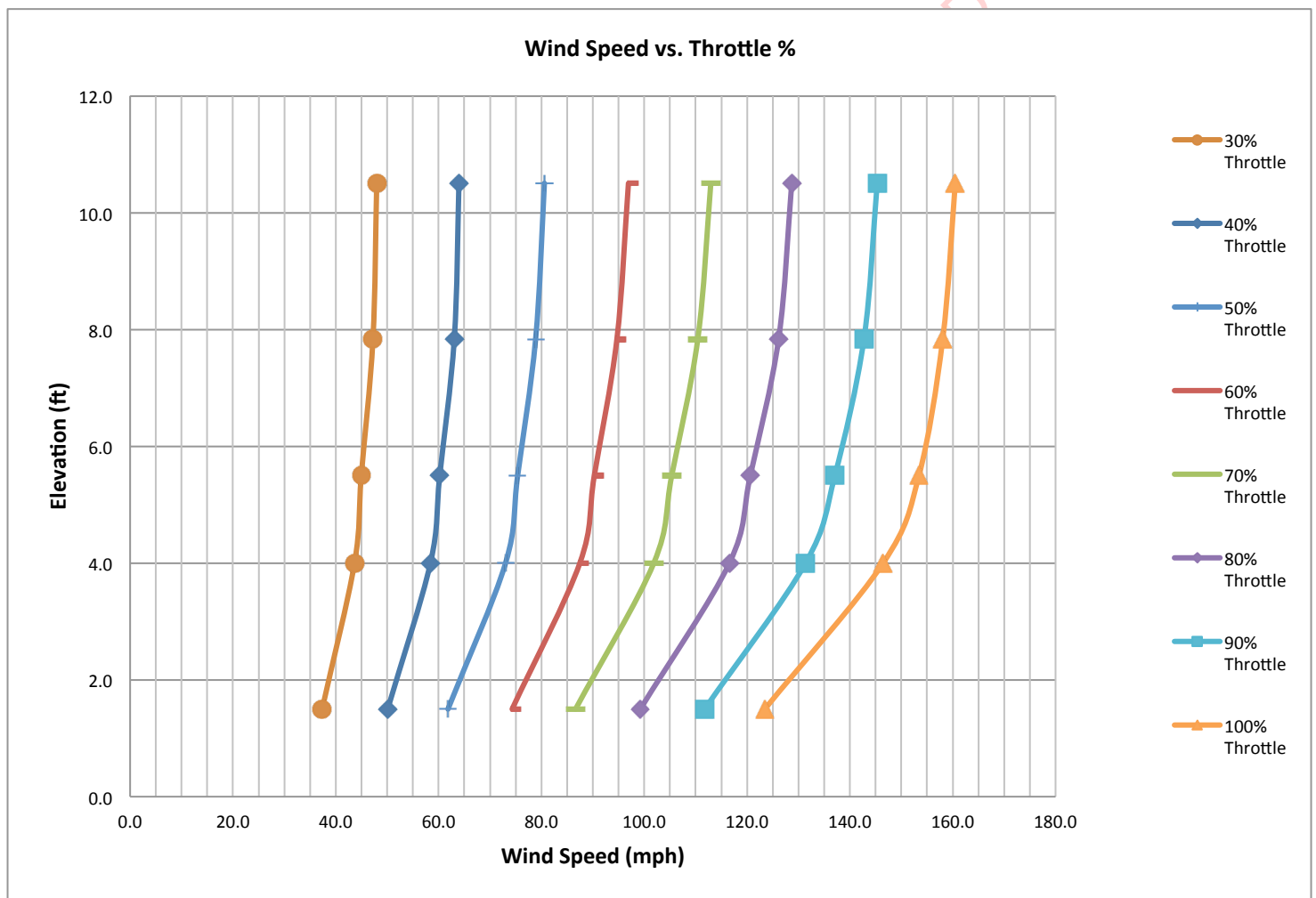
12-Fan Wall of Wind Boundary Layer Profiles

Setup: Open Terrain Spires, 9 inch Triangular Floor Roughness, 3.5 inch Cubic Floor Roughness

Measurements conducted on: 6/19/14

Free stream measurements location: center of the turntable.

Throttle %	30%		40%		50%		60%		70%		80%		90%		100%	
Height, z (ft)	mph	T.I. (%)	mph	T.I. (%)	mph	T.I. (%)	mph	T.I. (%)	mph	T.I. (%)	mph	T.I. (%)	mph	T.I. (%)	mph	T.I. (%)
10.5	48.0	4.2	64.0	4.9	80.6	4.4	96.9	4.5	113.0	4.2	128.7	4.3	145.3	4.2	160.5	3.8
7.8	47.2	5.4	63.0	5.2	78.9	5.2	94.7	5.2	110.4	5.0	126.1	4.9	142.7	5.0	158.1	4.6
5.5	45.0	6.4	60.2	6.0	75.4	6.1	90.3	6.0	105.3	5.9	120.6	6.0	137.1	6.0	153.4	5.9
4.0	43.6	7.3	58.4	7.0	73.0	7.1	87.5	7.0	101.9	7.0	116.6	6.6	131.4	6.7	146.5	6.5
1.5	37.4	12.7	50.1	12.8	61.8	12.7	74.3	13.0	86.6	12.4	99.2	12.5	111.7	12.0	123.5	12.3



Appendix B – Selection of test pictures

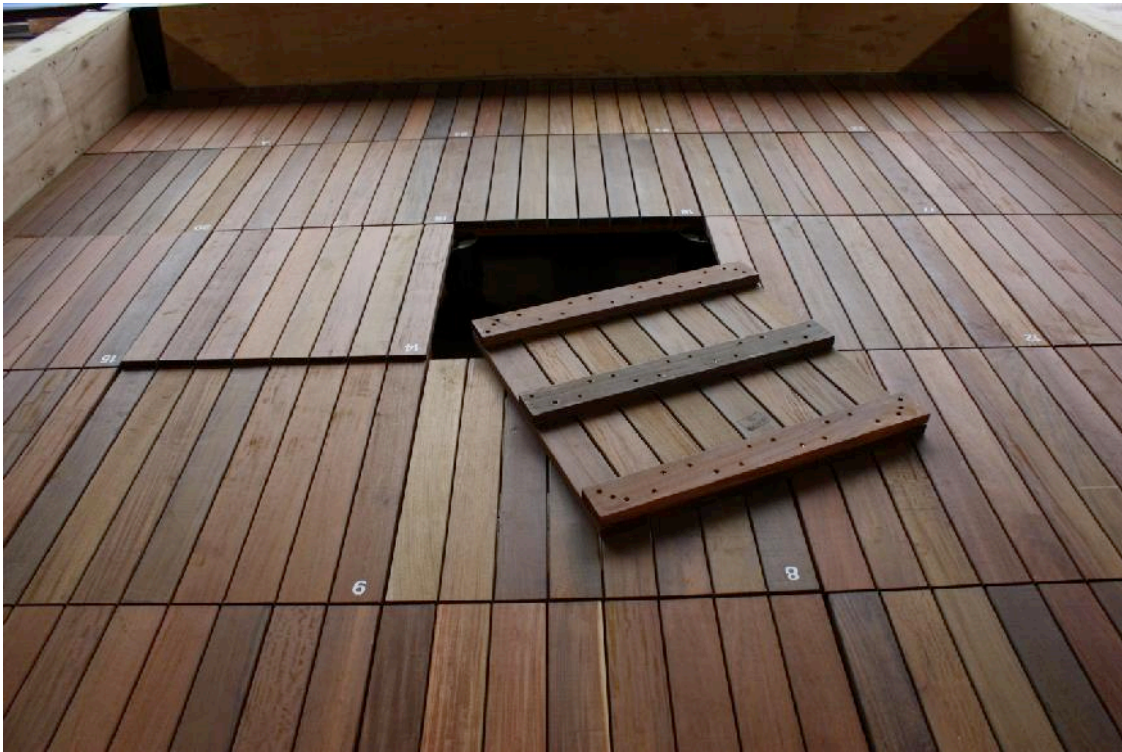


Figure 4 - Blown off wood paver at the parallel slats, 0 degree, 12-in parapet configuration



Figure 5 - Detail of the pedestal shifting/rotating by wind and shaking of pavers



Figure 6 - Pavers blown off pedestals; wind picked them up but didn't blow them off the roof. As they set down they fell onto the roof deck pushing away some of the adjacent pedestals



Figure 7 - Paver blown off into the leeward parapet

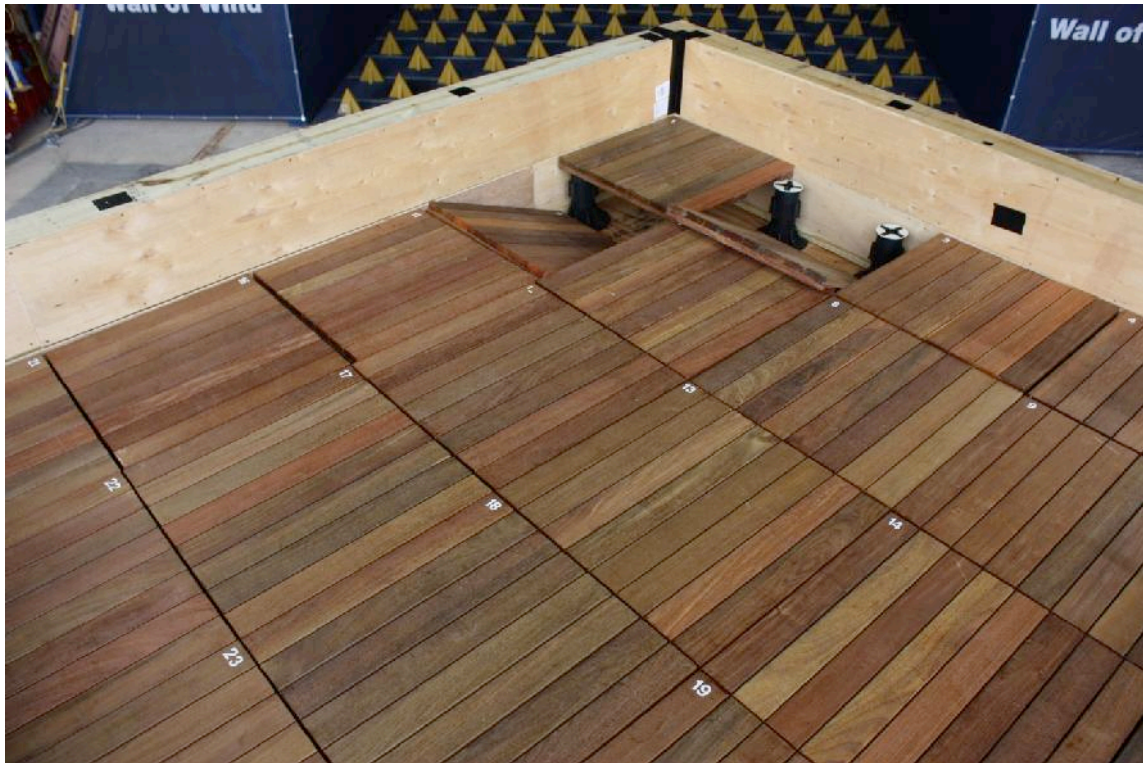


Figure 8 - Pavers picked up by the wind and shifted down. Wind angle is 45 degrees.

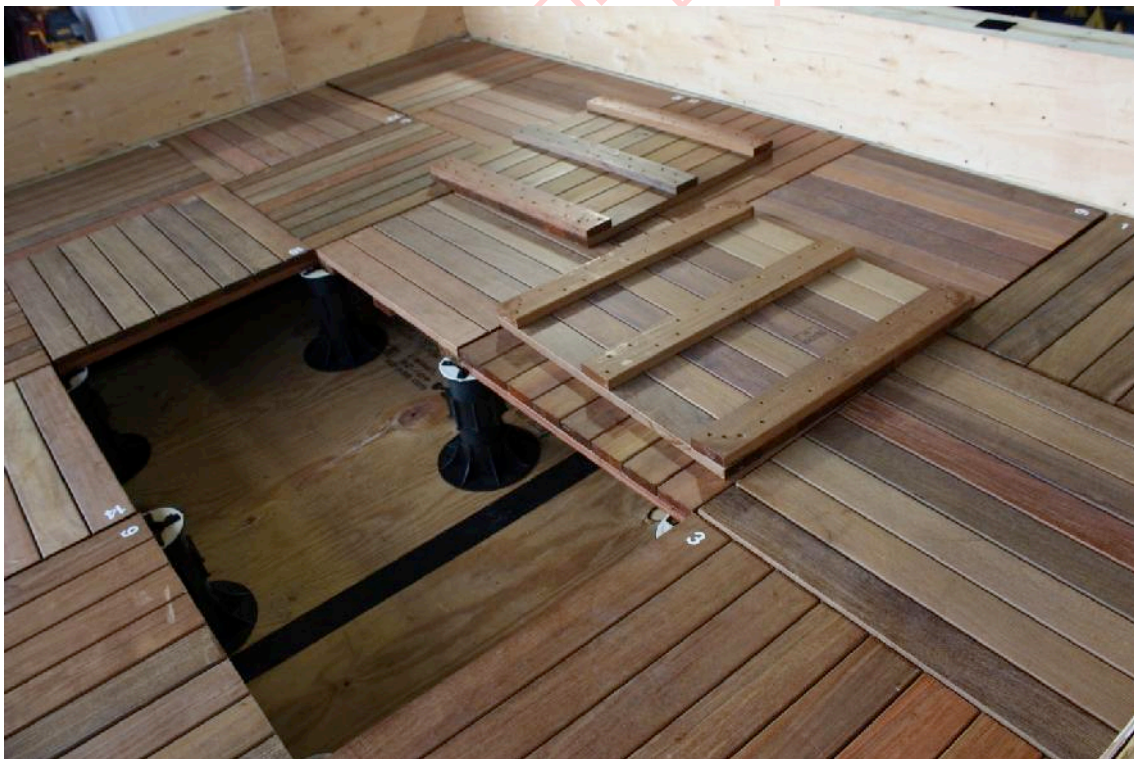


Figure 9 - Wood pavers laid out in basket wave configuration. The 2 pavers were flipped upside by the wind. Pavers were flipped in the direction of the oncoming wind.

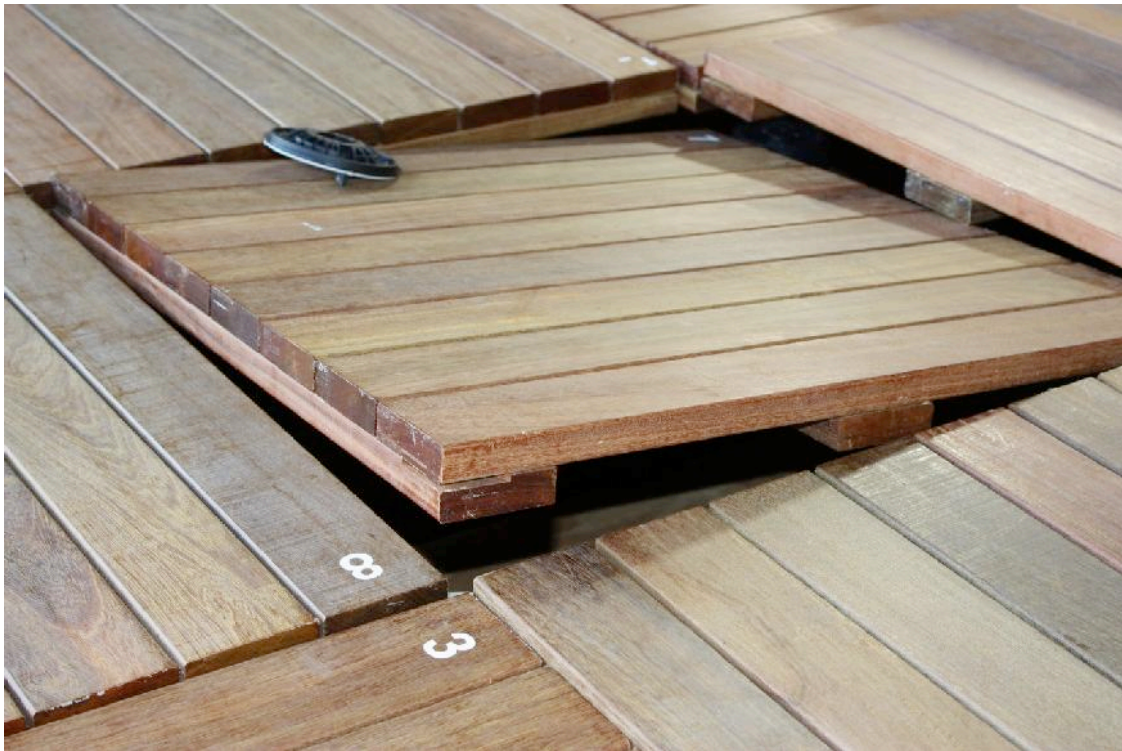


Figure 10 - Tilted paver after wind test. A loose pedestal plate cap may be seen on top of the paver. Shaking of the pavers loosens the caps and when the pavers start lifting allow the wind to pick up the plates. After that pavers no longer have the adequate support



Figure 11 - Detail of the perimeter paver locking devices



Figure 12 - Porcelain paver flipped upwards by the wind.



Figure 13 - Close up of a perimeter pedestal. Some rotation of the pedestal cap plate can be seen.



Figure 14 - Porcelain paver blown off by the wind from its location along the perimeter of the windward edge of the roof. A chipped corner may be seen on the paver from when it hit down.



Figure 15 - Pavers pushed down into the windward corner of the roof by the wind.

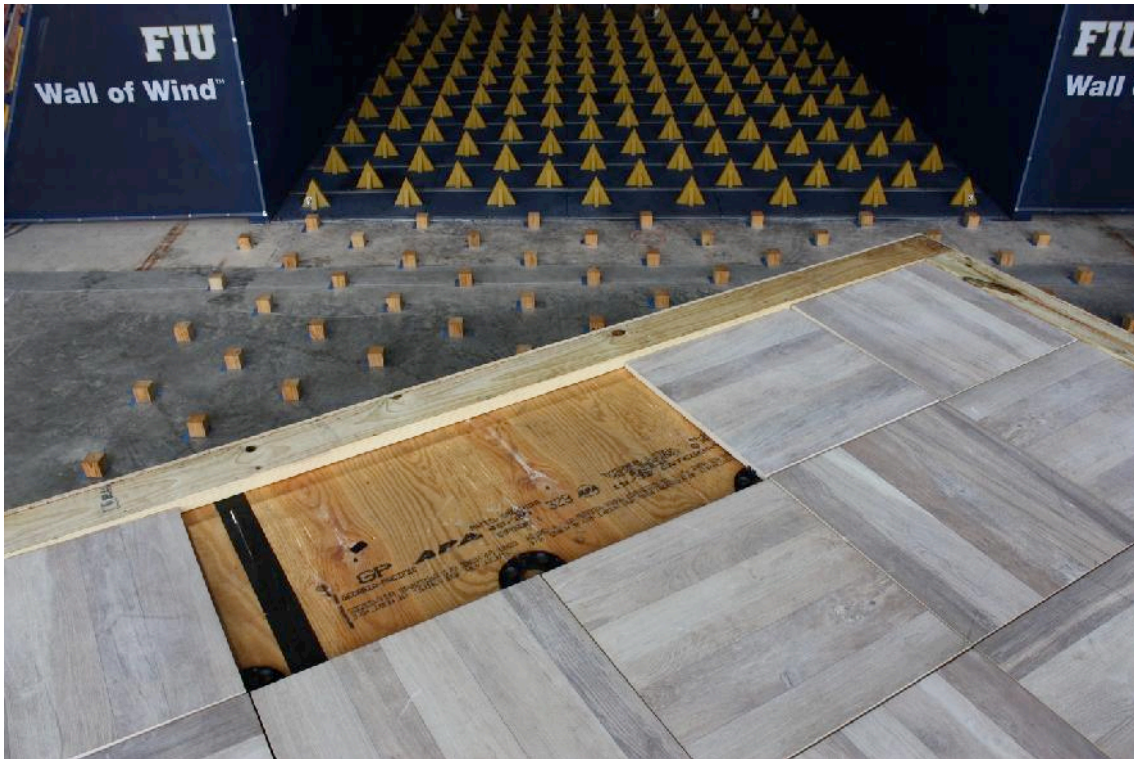


Figure 16 - Location of porcelain pavers blown off by the wind. These were thrown off the roof deck by the wind and shattered upon impact. the configuration had a fixed height pedestal and 0 in. parapet wall

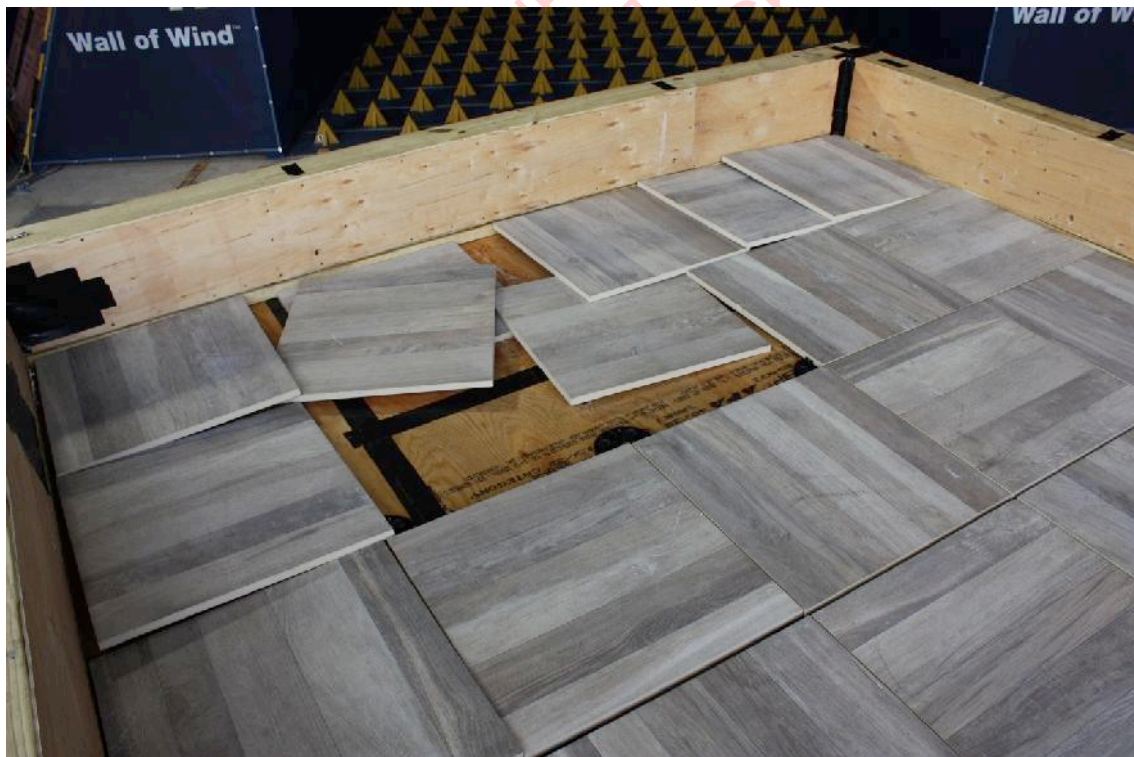


Figure 17 - Porcelain pavers moved around by the wind from their fixed-height pedestals. The 12-in parapet shelters the pavers from the wind but also produces some recirculation between the parapet walls. It can be seen on the picture that the wind pushed the pavers into the windward corner of the roof.