Technical Note

AERODYNAMIC UPLIFT PROPERTIES TESTING OF HYDROTURF® ADVANCED REVETMENT TECHNOLOGY

Extensive independent, third party aerodynamic testing has been performed on HydroTurf® Revetment Technology (HydroTurf) at the Florida International University Wall of Wind Experimental Facility at the International Hurricane Research Center in Miami, Florida, the Georgia Tech Research Institute Aerospace, Transportation and Advanced Systems Laboratory in Atlanta, Georgia, and at ViGYAN, a private research facility located in Hampton, Virginia since 1979. A description of aerodynamic testing procedures and test results are provided in this document. Additional testing and evaluations performed on HydroTurf include hydraulic jump, steady state and wave overtopping hydraulic performance and multiple non-hydraulic tests. Those testing descriptions and results are available in separate documents. Please contact Watershed Geosynthetics for additional information.

FULL-SCALE AERODYNAMIC EVALUATIONS

HydroTurf was tested for three distinct aerodynamic performance characteristics at three different facilities. Testing at the Florida International University Wall of Wind Experimental Facility determined HydroTurf performance in a "worst-case scenario" when installed on a flat roof. Georgia Tech Research Institute testing determined aerodynamic lift and drag forces acting on the tufted geosynthetic around the perimeter and at the interior of an installation. And, the ViGYAN facility tested HydroTurf response to wind gust conditions.

WALL OF WIND

The Wall of Wind Experimental Facility at the International Hurricane Research Center is an open jet wind tunnel with a combined 12-fan system capable of repeatable testing at wind speeds up to 157 miles per hour. The full-scale HydroTurf test was designed to evaluate infill options for roof installations in worst-case scenarios of an installation on a flat roof: high wind speeds (up to facility capacity), critical wind attack angle and parapet wall height ratio. Wall of Wind testing was conducted on a square, wooden building covering approximately 125 square feet and measuring five feet tall built on a rotating platform.

The simulated roof was constructed atop the building using plywood sheathing, free floating foam board (allowing uplift) and HydroTurf® with pea gravel infill. A 16-inch-high parapet surrounded the roof perimeter creating a worst-case building-to-parapet height ratio of 0.12 as previously identified by others[1]. The completed test structure is presented in Figure 1.

Figure 1: HydroTurf® Wall of Wind Test Installation

The test procedure utilized a wind profile representative of open terrain exposure, and a wind attack angle directly impinging the building face was considered zero degrees. Five wind attack angles were tested as presented in Figure 2. Tests began at a wind speed of 20 miles per hour and attack angle of zero degrees. At each tested attack angle, wind speed was incrementally increased each minute to the facility maximum wind speed, provided no observable lift or imminent failure was observed. The maximum average 1-minute wind speed was 150 miles per hour and the maximum 3-second gust was 151 miles per hour. Wind patterns and outlines of vortices were visible during testing. Testing in progress is presented in Figure 3. There was minimal gravel movement and no appreciable loss of infill. Infill thickness remained consistent across the roof and there was no evidence of scarifying of the infill. HydroTurf would make an excellent lightweight roof ballast and protection system, even in hurricane prone areas.

[1] Asghari Mooneghi, M. (2014). *Analytical and Experimental Methodologies for Predicting Peak Loads on Building Envelopes and Roofing Systems*, FIU Electronic Theses and Dissertations. Paper 1846. https://digitalcommons.fiu.edu/etd/1846/.

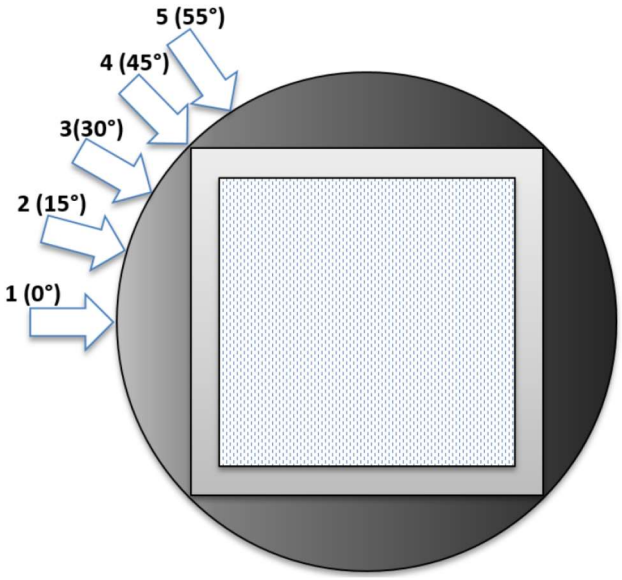

Figure 2. HydroTurf® Wind Attack Angles at the Wall of Wind

Figure 3. HydroTurf® Wall of Wind Testing in Progress

GEORGIA TECH RESEARCH INSTITUTE

The Georgia Tech Research Institute (GTRI) Aerospace, Transportation & Advanced Systems Laboratory subsonic model test facility tested the aerodynamic properties and ballast requirements of the tufted geosynthetic component of HydroTurf® at wind speeds up to 118 miles per hour. The full-scale test was designed to evaluate lift and drag forces acting on the tufted component of an installation around the perimeter and on an interior section. Results were used for determining required infill thickness to counteract wind induced aerodynamic lift.

The tufted component was tested in two configurations. The first test represented the perimeter of an installation**.** The second configuration represented the interior area away from the perimeter. Both installations were tested on a flat, level surface representative of level terrain.

GTRI testing was conducted on a 43 x 6 1/8 inch (width x length) full-scale installation. A plywood support base was overlain with foam representing a soil layer. The foam was covered with the geomembrane followed by tufted geosynthetic. During interior condition testing, larger installations were placed immediately upstream and downstream of the test section. During perimeter condition testing, the upstream tufted material was removed exposing the test section perimeter. The test configuration is presented in Figure 4.

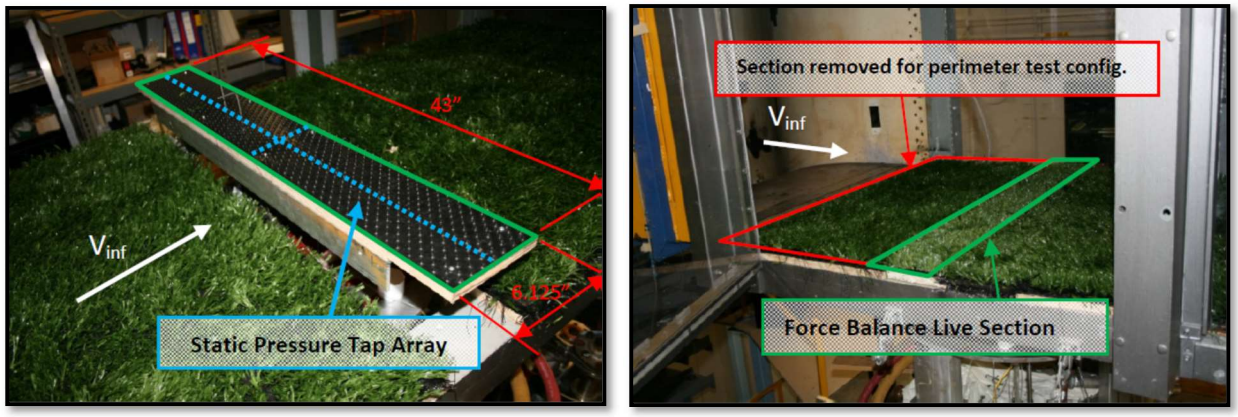

Figure 4. HydroTurf® GTRI Test Configuration

Test results were surprising: higher velocities produce less lift and require less infill material. Figure 5 presents perimeter condition testing in progress at 118 miles per hour (174 feet per second). The inset figure displays the perimeter lift force data measurements increasing at lower velocities, peaking at approximately 44 miles per hour (65 feet per second) and steadily decreasing. Interior conditions exhibited a similar increasing/decreasing lift force pattern.

The HydroTurf® system disruption of the boundary layer and downward flexing blades naturally decrease system uplift at higher velocities. These properties in conjunction with HydroBinder® infill, produce a stable installation in hurricane force winds when properly designed, constructed and maintained.

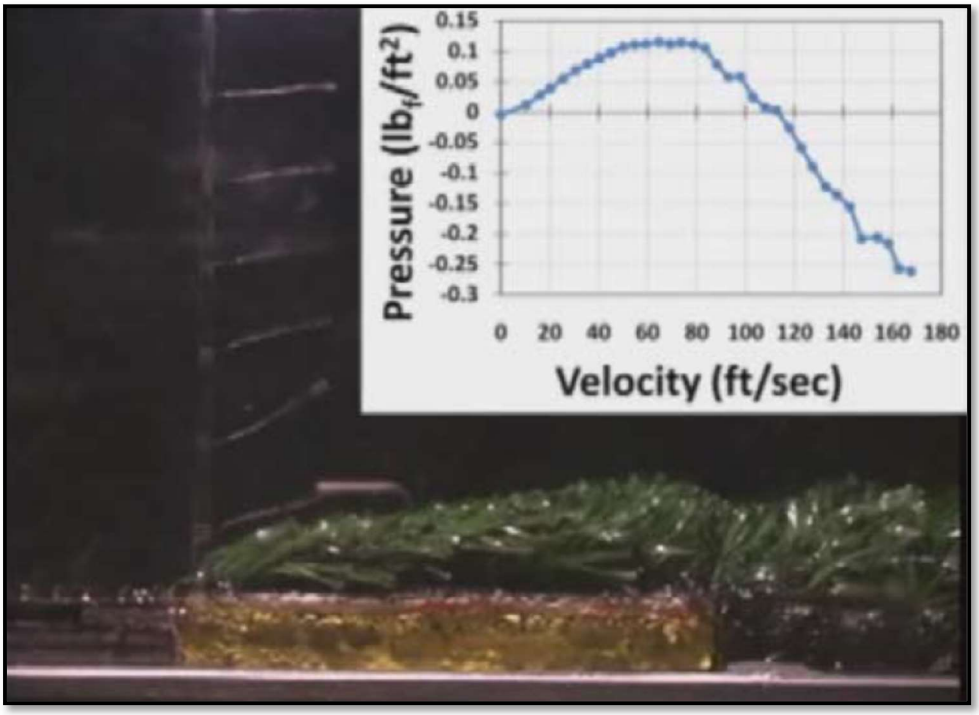

Figure 5. HydroTurf® Lift and Drag Testing at GTRI

ViGYAN

The ViGYAN Inc. wind tunnel is located in the Aero-Fluids Laboratory building at the Langley Research and Development Park in Hampton, Virginia. The open return design tunnel has been serving the aerodynamic testing requirements of government agencies and commercial customers since 1988 in addition to supporting on-going, internal research and development. The full-scale testing assessed resilience of an interior section of the HydroTurf® tufted geosynthetic component to a sudden gust of wind.

ViGYAN testing was conducted on a plywood base measuring 4 feet by 6 feet (width x length). Three sections of tufted geosynthetic each measuring two feet wide (6 feet total) were installed on a plywood base. The upstream and downstream sections were secured to the plywood base with heavy duty double-sided tape. The middle section was secured to the plywood base at the downstream edge, only. As a safety precaution, thin wire was also secured across the sample to prevent the sample from blowing down the tunnel if it were to pull completely away from the ground board. The product installation is presented in Figure 6 prior to placement in the wind tunnel.

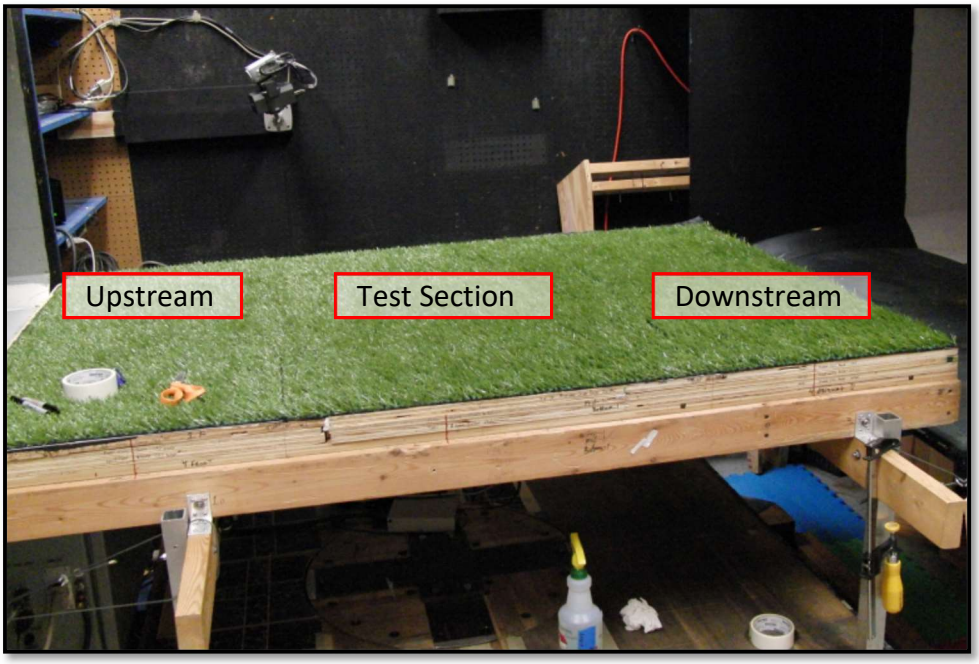

Figure 6. HydroTurf® Wind Gust Testing at ViGYAN

During testing, three video cameras recorded the installation with instantaneous wind speed overlain on the video feed. One of the cameras was positioned to provide a side view of the installation to capture any movement, should movement occur. Initial wind speed was approximately 26 miles per hour. Once a wind gust began, peak wind speed for the gust was attained within 2-3 seconds.

After 22 wind gust tests and a maximum gust speed of 110 miles per hour, the tufted geosynthetic did not pull away from the installation. The installation remained in place.

LIMITATIONS