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WIND SPEEDS IN A PARKING GARAGE DURING A HURRICANE AND USE OF A PARKING GARAGE AS AN EVACUATION REFUGE OF LAST RESORT

T.W. Schmidlin[1]*, B. Hammer[1], P.S. King[2], L.S. Miller[3], G. Thumann[3], H. Wetherington[4]
[1]Department of Geography, Kent State University, Kent OH
[2]Boyce Thompson Institute, Cornell University, Ithaca NY
[3]Department of Aerospace Engineering, Wichita State University, Wichita KS
[4]Division of Emergency Management, Palm Beach County, West Palm Beach FL

1. INTRODUCTION

A hurricane evacuation may be halted prior to landfall. If evacuation is stopped, thousands of motorists may be caught on the highways, in regions unfamiliar to them, for the duration of the hurricane and be exposed to the hazards of high winds and heavy rains. A refuge of last resort (RLR) is a place of short-term mass shelter that does not meet strict requirements of a hurricane shelter, but provides some refuge from the storm and safer exposure than an outdoor highway location. In a worst-case scenario, when thousands remain on the highway when evacuation is stopped, the RLR may provide a measure of safety, or refuge, for large numbers of people.

One possible RLR is the above-ground, multi-level, parking garage, commonly located in urban and suburban areas along major highways. Most parking garages are multi-level engineered concrete structures that will withstand hurricane force winds. However, parking garages have large openings to the outside to provide ventilation and light and these openings will allow wind to enter the garage during a hurricane. The purpose of this research was to study the wind patterns inside a parking garage during a hurricane and assess the feasibility of using parking garages as RLR during a hurricane.

2. WIND MEASUREMENTS IN A PARKING GARAGE DURING HURRICANE ISABEL

Field work to measure wind speeds inside a parking garage during a hurricane was conducted on 18 September 2003 during Hurricane Isabel. Hurricane Isabel made landfall as a Category 2 hurricane near Cedar Island, North Carolina, about 55 km northeast of Morehead City, on 18 September. Our field team (Schmidlin, Hammer, King) chose the Dominion Tower Parking Garage in Norfolk for the study. It is located on the north shore of the tidal Elizabeth River at the edge of downtown Norfolk, about 2 m above sea level. The garage is 82 m long and 70 m wide and has 7 parking levels. The garage has rectangular openings on three sides beginning 1.1 m above the floor that are 1.1 m high and 5.5 m to 8.5 m long. The garage is enclosed on the west side.

*Corresponding author address: Thomas W. Schmidlin, Dept. of Geography, Kent State Univ., Kent OH 44242; e-mail: tschmidl@kent.edu.

Continuous measurements of wind speed during the hurricane were collected with an Onset Hobo micro-logger with three anemometers inside the garage and one anemometer and wind vane outside. The outdoor anemometer and wind vane were placed on the open 8th floor roof of the parking garage, 24 m above the ground, on the NNE-facing (20^o) upwind edge of the roof. Two anemometers were placed on the second level of the parking garage, one 6 m from the upwind side, and the other 30 m from the upwind side to represent the interior of the garage. A fourth anemometer was placed on the third level, 6 m from the upwind side and directly above the anemometer on the second level. Hand-held anemometers were used to take one-minute measurements of mean wind speed and peak gust on a dense grid on the second level of the garage.

3. RESULTS

The maximum 3-second gust outdoors was 32 ms^{-1} (71 mph) and the maximum "sustained" wind, defined by the National Hurricane Center as the fastest one-minute average, was 22 ms^{-1} (48 mph). Wind direction was 50^o to 60^o and then turned gradually to 110^o at about 17:15. After this time the "upwind" anemometers on the second and third floors of the garage were no longer considered to be upwind.

The anemometer on the second floor about 6 m from the upwind openings had a maximum one-minute mean wind speed of 6 ms^{-1} and a maximum gust of 11 ms^{-1}. Wind speeds at this site were similar to the winds on the third floor directly above. Mean wind speeds averaged 26% of the outdoor mean wind while the site was upwind and then fell to about 10%. Gusts at this second floor upwind site averaged 33% of the outdoor gusts while the site was on the upwind side of the garage, and then dropped to about 15%.

The anemometer on the second floor about 30 m from the upwind openings, and representative of the interior of the garage, had a maximum one-minute mean wind speed of 4 ms^{-1} and a maximum gust of 7 ms^{-1}. Mean wind speeds at this interior site averaged 10% of the outdoor mean wind speed and gusts averaged 16% of the outdoor gusts.

Wind was measured with hand-held anemometers at 44 locations on the second floor of the parking garage, including on wide, straight parking ramps leading to the 1st and 3rd floors. Four one-minute measurements were made through the day at each of the 44 sites. The mean wind speed and maximum gust for each of these measurements was divided by the mean wind speed and maximum gust measured outdoors for the same minute. This gave a ratio between indoor wind speed and outdoor wind speed. The ratios were then averaged to give a mean ratio for each site. This provided a standardized ratio of indoor versus outdoor wind speeds at each of 44 sites on the second floor over a variety of wind speeds through the day.

For one-minute mean wind speeds, the indoor wind was strongest within about 6 m, or about one parking space, of the upwind north and east walls of the garage. The indoor mean wind speeds here were 30% to 40% of the outdoor wind. However, beyond 6 m from the upwind sides, the indoor winds were 20% to 30% of the outdoor wind through most of the garage and fell to 10% to 20% in portions of the interior. For maximum gusts, the indoor wind was again strongest within about 6 m of the upwind north and east sides of the garage. The indoor gust speed here was 35% to 45% of the outdoor gust speed. For most of the garage, the indoor gust speeds were 20% to 30% of the outdoor gusts.

In summary, windward openings in the garage allow strong wind to enter but the expansion of volume encountered by the winds passing through a 1.1 m high opening into the 2.9 m tall space of the parking garage causes a rapid decrease of wind speed within 2 m to 4 m of the upwind openings. Indoor winds are typically less than 35% of the outdoor winds 6 m into the garage, and fall below 30% through most of the garage. These ratios between indoor and outdoor wind speeds were consistent over the range of outdoor gusts from 14 ms^{-1} to 32 ms^{-1}, although we cannot rule out a change in the ratio at higher wind speeds. If the interior garage ratio remains nearly constant (~30% at the upper portion of the range) with increasing winds, then outdoor gusts as high as 90 ms^{-1} (200 mph) will produce gusts of less than 27 ms^{-1} (60 mph) in a parking garage, except within one parking space of the upwind side. Gusts to 27 ms^{-1} are unlikely to move or tip passenger vehicles (Schmidlin et al 2002).

4. WIND TUNNEL EXPERIMENT

A 1:59 scale model "generic" parking garage scaled to fit in the Wichita State University 2.1 m x 3.1 m wind tunnel, was built in the National Institute for Aviation Research Engineering Research Shop. To simplify the investigation experimentally, a uniform atmospheric boundary layer and no particular garage setting, surroundings, or landscape was assumed. The installation isolated the model from the wind tunnel floor boundary layer and helped to assure uniform approach flow conditions. This installation defines a conservative or worst-case situation. The ground board and model was rotated at 15 degree increments over a range of 360 degrees, to simulate different wind directions. Irwin Probes measured local flow speeds. These probes are omni-directional in response. Thermal anemometry, applied prior to extensive testing, validated the Irwin Probe data. A tunnel wind speed of 67 ms^{-1} was used in the testing.

In general, model wind speeds inside the garage were strongest at the narrow, upwind sides of the garage where wind speeds were near or slightly above outside wind speeds. When the narrow side was downwind, the inside wind speed was less than 50% of outside wind speed and, in some cases, near calm. The strongest winds, 125% of outside wind speed, occurred at the corners when the wind was coming toward that corner. Along the longer sides of the model garage, inside wind speeds were 50% to 100% of outside wind speeds when that side was upwind and generally less than 75% when that side was downwind.

The results of the wind tunnel experiment were similar to our results inside the parking garage during Hurricane Isabel. Winds inside the model garage were 50% or less of outside wind speeds for most wind angles. However, in contrast to our results during Hurricane Isabel, the wind tunnel results indicate that winds inside the garage near the upwind openings can be as strong as, or stronger than, outside winds.

5. CONCLUSIONS

There are many issues to consider related to using an above-ground, multi-level parking garage as a Refuge of Last Resort for motorists when evacuation is stopped during a landfalling hurricane. The garage must be structurally sound and not at risk to fail during high winds. Its access must not be restricted by storm surge or freshwater flooding. It must have space for vehicles of evacuees and be of sufficient height to permit entry of the taller passenger vehicles. A garage with glass in openings, as seen in one garage in Norfolk, should be avoided.

The wind data collected in a parking garage during Hurricane Isabel showed that wind speeds inside the garage are much less than outside. This was true at all locations observed within the garage and throughout our eight hours of data collection. This conclusion was supported by results of a wind tunnel experiment with a 1:59 scale model parking garage, except that winds in the model garage were shown to be as strong as outside winds near upwind corners and near openings on the narrow, upwind side of the garage.

The most dangerous places in a parking garage during a hurricane are within 6 m of the upwind openings, or about the first row of parking spaces. Winds strong enough to cause substantial damage to vehicles or upset vehicles are unlikely inside a parking garage, even in much stronger outdoor winds than studied during Hurricane Isabel.

6. ACKNOWLEDGEMENT

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7. REFERENCE CITED

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