Estimating the 3-Second Gust on Rooftops of Residential and Low-Rise Buildings during a Hurricane

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Abstract

After the passage of a hurricane numerous infrastructures suffer water and wind damages. From engineering meteorology viewpoint, many cases are related to the impact of the wind on a roof. In order to estimate the wind speed on a roof, the three second gust is employed according to ASCE-7 for the wind load analysis. However, since there is no 3-s gust measurement on a roof, constant disputes occur as to who is liable to pay for the damages. After a brief review of recent literature, this technical note provides a methodology to resolve these disputes objectively. The formula is verified by full-scale field measurements during Hurricanes Frances an Ivan. Furthermore, in order to help engineers and contractor estimate the 3-s gust on the rooftop, methods are provided so that the needed 3-s gust can be computed from wind speed measurement available routinely from airports.

Index terms— wind speed on roofs; rooftop jet; gust factor; turbulence intensity; hurricanes

1 Introduction

uring a tropical cyclone along hurricanepronecoastal regions, many residential and lowrise buildings suffer structural damages, particularly their roofs. When the 3 second gust on a roof exceeds 33 m/s (74 mph), insurance companies should pay for these damages. However, many disputes occur between the insurance companies (representing the contractors) and the lawyers for the insurers because it is usually difficult to estimate the 3-s gust speed. The purpose of this technical note is to help engineers and contractorsso that estimation of3-sgust on roofs can be made objectively during hurricanes.U 2 / U 1 = (Z 2 /Z 1) P (1) Z 2 > Z 1

Where U 2 and U 1 are the wind speed at height Z 2 and Z 1 , respectively, and P is the exponent.

Eq. (**??**) has been used widely inengineering community (see e.g. ASCE 7-02, in Irwin, 2006). The relationship between Eq. (**??**) and the more theoretically based logarithmic wind profile is provided in Hsu (1988). For detailed information relating the gust factor and the exponent P, see Hsu (2003 and2008).

2 II.

Relationship Between G and P Since one minute sustained wind speed is used by the National Hurricane Center (see www.nhc. noaa. gov), from Hsu (2008), we haveG = 1 + 1.96 P = 1 + 1.96 TI (2a)

Where G is the gust factor (the ratio of 3-s gust to 1-min sustained wind Speed) and TI represents turbulence intensity.

Similarly, for 5 second gust over 2 minute period as used in wind speed measurements by the Automatic Surface Observing System (ASOS) station at airports worldwide,G = 1 + 2.04 P = 1 + 2.04 TI (2b)

Where G is the gust factor (the ratio of 5-s gust to 2-min sustained wind speed) and TI represents turbulence intensity.

Further verification of G versus P is demonstrated in Fig. **??** for an industrial park (Crandell et al., 2000). It is clear that a linear relationship between G and TI or P exists so that, G -1 = 2.13 TI (3a) Or G = 1 + 2.13 TI (3b) R 2 = 0.91, indicating that 91% of the total variation of G can be explained by TI. Therefore, TI or P can be determined from the gust measurements such as at airports. In the atmospheric boundary layer, the wind speed increases with height according to the power law such that III.

3 Review of Recent Literature

From engineering meteorology viewpoint, most cases dealing with buildings damaged by a tropical cyclone are related to the roofing system. In fact, during Hurricane Katrina in 2005, the roof of Louisiana Superdome in New Orleans, Louisiana, suffered severe damages. In addition, countless roofs in low-rise structures were destroyed by the gusty wind associated with Katrina.

Before cases are studied, some reviews of recent literature are helpful:

When air flows in a street canyon, Christen et al (2009) found that the highest turbulence intensity was located at 1.5 times the building height as depicted in Fig. **??**. Therefore, on the basis of Eq.(**??**a) and (2b), the gust factor is about two, meaning that the gust speed can be more than twice the sustained wind speed.

Because of this high gust speed we will name it as the rooftop jet. Note that at the rooftop edges and eaves, the gust factor can be 1.96 because TI = 0.48.

According to Aponte-Bermudez et al (**??**006), the average ratio of 3 second gust over one minute sustained wind speed for 10 residential houses in Florida during 5 hurricanes was 1.82 with a small standard deviation of 0.16. This means the coefficient of variation is only 9% (i.e. 0.16/1.82 = 0.09), which is within the 10% error margin for the wind measurements as stated previously.

Measurements and computations for flow and turbulence in simulated city canyon were investigated by Zajic et al (see www.geo.uni.lodz.pl/ ~icuc5/text /0_33_4.pdf). They found that the velocity U h at the building height h correlates well with the wind speed U r at the reference height Z r for the first row of containers according to a power-law profile such thatU h /U r = (h/Z r) 0.53**(4)**

Finally, in an urban area such as New York City during Hurricane Irene in 2011, the gust factor from ASOS station at Central Park was 1.86 whereas in its vicinity at LaGuardia and Kennedy Airports, the gust factors are 1.29 and 1.28, respectively (see Avila and Cangialosi, 2011). Substituting these gust factors into Eq. (2b), we get TI = 0.42 for the Central Park and 0.14 for the two airports nearby. These values are consistent with literatures in that p = 0.40 for the urban area and 0.16 for the flat open country known for a long time (see Davenport, 1965). The TI (=0.42) is also in agreement with Fig. **??**, since the ASOS station in the Central Park is located near the top of many trees and some buildings. IV.

4 Full-Scale Measurements During Hurricanes

Full-scale measurements for hurricane wind loads on residential structures were made by Aponte-Bermudez et al **??**2006). Their results are summarized in Table 1.

5 Hurricane

House

6 Objective Methodology

According to Marshall (see http://ams.confex. com/ams/ pdf papers/137547.pdf) , during Hurricane Katrina, there was an anemometer located at 1.5m above the southeast roof corner on a 16m high building at Ingalls Shipyard in Pascagoula, Mississippi, USA. That anemometer recorded 3-second wind gust up to 53 m/s. On the other hand, an anemometer located at nearby Trent Lott International Airport recorded a peak 3-second gust of 41.6 m/s at 10m. These precious data provide us an opportunity to verify Eq. (4) as follows:

By setting U r = 41.6 m/s, h = 16 m (the roof height), and Z r = 10m into Eq. (**??**), we have U h = 53 m/s, which is the same as measured.

Further verification of Eq. (4) is provided in Table 1. Since the difference between the two means (i.e. 33.8 m/s as measured on rooftops versus 33.0 m/s as estimated by Eq. (4)) is only 2.4%, Eq. (4) is also very useful for estimating the 3-secondgust impacting on the rooftop by hurricanes. Note that the 3-s gust is needed to determine whether the insurance companies are liable to pay the home-owners. In U.S., if the 3-s gust exceeds 33 m/sor 74 miles per hour as Category One 0.45, 2.17 Hurricane, the insurance company usually reimburses the home-owner to replace the roof damages.

On the basis of foregoing analyses, it is recommended that for the estimation of three second wind gust impacting on a building, Eq. (4) can be employed to determine the rooftop jet speed. This finding should be very useful for structural engineers as well as insurance industry, since constant disputes occur between the insurance companies and insurers. Now, we can apply Eq. (4) to determine objectively the magnitude of the 3-second gust on a rooftop using the 3-second gust measurement from ASOS station normally located at airports. If the 3-s gust is not available from ASOS, remedial methods are provided in the next section.

7 VI.

Estimating the Three-second Gust from ASOS Measurements

Because the 3-second gust data is not always available, we need to estimate it from the 2-minute sustained wind speed, which is routinely measured and reported from ASOS station at airport. On the basis of simultaneous wind speed measurements between ASOS and Texas Tech stations during Hurricane Bonnie as provided in Table 2 (see Schroeder, 1999) we can get the needed 3-second gust by multiplying the 2minute sustained wind speed by a factor of 1.38. This factor is obtained from the ratio of 33.6/24.4 = 1.38.

8 Conclusions

On the basis of aforementioned analyses and discussions, we conclude that the three second gust impacting on residential or low-rise building roofs during a hurricane can be determined from Eq. (4) objectively. Methods are also provided that the needed 3-s gust can be computed from the routine wind measurements at the airports. These methods should help engineers and contractors resolve the disputes arising from damages caused by a hurricane. However, since the wind profile varies with the terrain exposure, adjustment of terrain transition needs to be taken into account [1] [2] [3]

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Figure 1: Figure 1 :Figure 2 :

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[Note: rise Residential Buildings during Hurricanes in 2004 (Data Source: Aponte-Bermudez et al., 2006)]

Figure 2: Table 1 :

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measurements of wind speeds as obtained via Texas Tech University and ASOS Stations for Hurricane Bonnie (Data source: Schroeder, 1999). Unites are in m/s

	ASOS Station	Texas Tech Station
0.2-Second Gust	NA	38.2
3-Second Gust	NA	33.6
5-Second Gust	32.9	33.5
1-Minute Sustained	NA	25.0
2-Minute Sustained	25.2	24.4

VIII.

Figure 3: Table 2 :

[Global Journal of Researches in Engineering] , *Global Journal of Researches in Engineering*

[Electronic J. Structural Engineering ()] , *Electronic J. Structural Engineering* 2008. p. .

[Hsu ()] *Coastal Meteorology*, S A Hsu . 1988. San Diego, CA: Academic Press. p. 260.

[Hsu ()] *Estimating 3-second and Maximum Instantaneous Gusts from1-minute Sustained wind Speeds during a Hurricane*, S A Hsu . 2008.

[Hsu (2003)] 'Estimating Overwater Friction Velocity and Exponent of Power-Law Wind Profile from Gust Factor during Storms'. S A Hsu . *J. Waterway, Port, Coastal and Ocean Engineering* 2003. July/August 2003. p. .

[Irwin (2006)] 'Exposure Categories and Transitions for Design Wind Loads'. P A Irwin . *J. Structural Engineering* 2006. November 2006. p. .

[Schroeder ()] *Hurricane Bonnie Wind Flow Characteristics, a Dissertation in Civil Engineering*, J L Schroeder . 1999. Texas Tech University (Accepted in December1999)

[Aponte-Bermudez and Gurley ()] 'Hurricane wind loads on Residential Structures: Full-Scale Measurements and Analysis from'. L D Aponte-Bermudez , K Gurley , Reinhold , T . *Fourth LACCET International Latin American and Caribbean Conference for Engineering and Technology (LACCET 2006), "Breaking Frontiers and Barriers in Engineering: Education, Research, and Practice*, (Mayaquez, Peurto Rico) 2006. 2004 and2005. June 2006.

[Marshall] T P Marshall . `http://ams.confex.com/ams/pdfpapers/137547.pdf` *Wind Versus Water Damage to Buildings: A Meteorological Perspective*,

[Crandell et al. ()] 'Near-ground Wind and its Characterization for Engineering Applications'. J H Crandell , W Farkas , J W Lyons . *Wind and Structures* 2000. 3 (3) p. .

[Christen et al. ()] 'The Budget of Turbulent KineticEnergy in the Urban Roughness Sublayer'. A Christen , M W Rotach , R Vogt . *Boundary-Layer Meteorol* 2009. 131 p. .

[Davenport ()] 'The Relationship of Wind Structure to Wind Loading'. A G Davenport . *Her Majesty's Stationary Office*, (London) 1965. 1965. p. . National Physical Laboratory

[Avila and Cangialosi (2011)] *Tropical Cyclone Report*, L A Avila , J Cangialosi . `Availableonlineatwww.nhc.noaa.gov` 2011. August 2011. Hurricane Irene(AL092011. p. .