Engineering Guidance regarding Wind-Caused Damage Descriptors

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Terms of Reference

The reviewers were asked to provide guidance regarding the wind-caused damage descriptions in the proposed Saffir-Simpson Hurricane Wind Scale (SSHWS), a modification of that originally adopted from Simpson (1974). Two descriptions were provided.

- "Local" descriptions to be issued in the advisories, which are provided in Version 10 of the document developed by the CTA Review Team (NOAA-NWS 2008). Detailed information is provided for <u>eight</u> wind speed regimes spanning tropical depression to major hurricane conditions. The dependency of surface wind speed intensity on terrain is discussed in this document.
- Descriptions that are generalized for the <u>five</u> SSHWS categories. This information appears in the 10/30/2009 Saffir-Simpson Hurricane Wind Scale Document (NOAA-NHC 2009). These damage descriptions are critiqued at the end of the document.

Summary Recommendations

While there are many aspects of a simplified "one size fits all" damage scale that can be critiqued, and we allude to many such issues below, we have suggested some minor additions and changes to the various category descriptions that might assist in the SSWHS team deliberations in the immediate future.

We would recommend that a more comprehensive analysis could be undertaken that might better consider many of the issues that we have identified and provide a firmer basis for a new scale that would be best suited to future needs. In particular we encourage more appreciation of the effects of terrain, topography and gustiness on forecast winds generally, and the links with the 1-min sustained wind metric and the standard design 3-sec gust metric that underpins design resilience. We also encourage the consideration of published peer-reviewed research on alternative scales to convey damage potential (e.g. Kantha 2006, Powell and Reinhold 2007) as well as the need for an interdisciplinary approach the problem. In regards to the CTA use, we recommend that extensive post analysis be conducted to determine an "Analysis of Record" that uses standardized observations to determine the peak sustained and gust winds experienced throughout the CTA warning areas. Verification of the warning conditions against what actually happened will provide an assessment of the CTA condition error an also provide feedback so the public understands the wind conditions they most likely experienced.

1. Wind Speed Regimes

The expected damage state is conditional to the site-specific wind speed. For reference, the wind speed regimes defined in the CTA document are provided in Table 1.

Table 1. CTA Wind Speed Regimes

Sustained	30-40	40-50	50-60	60-75	75-90	90-110	110-130	130-160
Gusts	50	65	80	90	110	135	155	170+

Neither of the wind advisories specifies if the wind speeds occur over water or land. It is understood that the SSHWS refers to the maximum sustained (1-min) wind speed at 10 m height that is estimated to be associated with the storm anywhere in the entire circulation (land or water). However, it does exclude extreme wind speeds that may be associated with squalls, meso-vortices, and embedded tornadoes.

The CTA gust duration and observation period are not stated but it is assumed here that they are likely to be of 3-sec duration within a 10-min observation period. This issue needs to be resolved because the expected severity of damage is most commonly associated with the local gust wind speed, which is dependent on the upwind terrain conditions.

Figure 1 contains a plot of the CTA gusts versus the sustained wind speed regimes, which are assumed to be 1-min averages. The 3-sec gust values for the equivalent marine-, open- and suburban-exposure conditions are also included for the lower and upper bound of each wind speed regime. The values were determined using standard boundary layer conversion techniques (see Vickery and Skerjl 2005 or Harper et al. 2008). As an aside, this figure can be used to convert peak gust speeds occurring in a 30 min to 1 hr period—perhaps it can be of use to the forecasters.

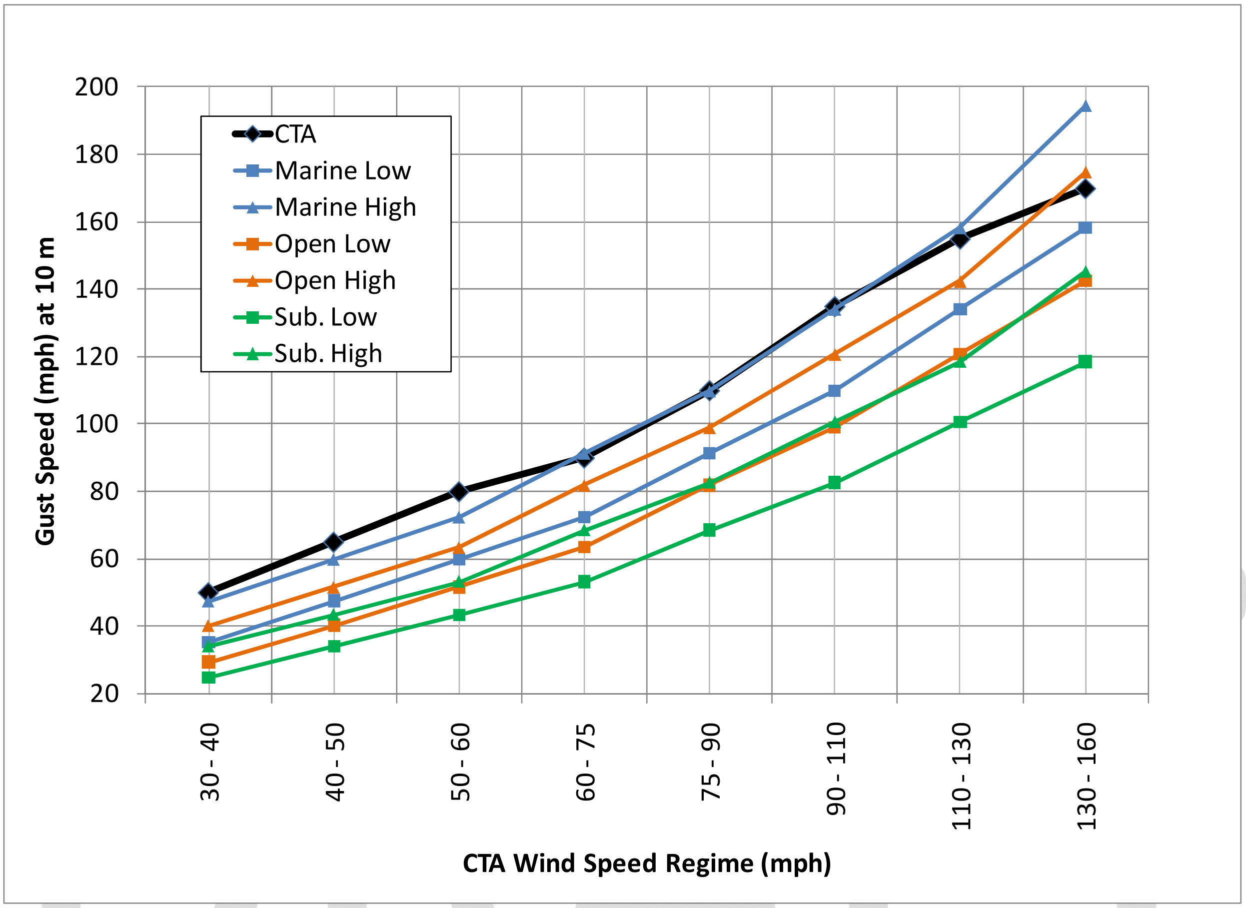

Figure 1. Terrain dependent gust speeds based on the CTA wind regimes

Based on the good agreement between the marine 3-sec gust estimates and the published CTA values, it appears that the CTA wind gusts were derived from the upper bound wind speed values (40, 50, …, 130 mph) assuming they correspond to marine exposure.

The gust speed range over the various terrains varies from 30 mph at low end to 70 mph at the high end. The major implication is that for a given wind speed regime, the damage to the built and natural environment will vary widely.

Predicated on the assumption that the damage descriptions are being used as an advisory and warning tool for the general public, a logical choice would be develop them from the most extreme conditions. Based on this assumption, the damage descriptions presented herein have been calibrated to match the upper bounds of the marine and open exposures. The marine gusts will only be appropriate for communities within ~½ mile of the coast. The open or suburban exposure gusts will be appropriate for communities more inland.

Recommendation: Consider adjusting the gust speeds to match the expected gust values shown in Figure 1 (the ‘marine high’ curve). The gust speeds in the lower regime require a slight downward adjustment, while the gust speeds in the uppermost regime require an upward adjustment.

2. Regional Building Performance

Design wind speeds in the USA are determined from the American Society of Civil Engineers' *Minimum Design Loads for Buildings and Other Structures* ASCE 7-05, (ASCE 2006). Appendix A (Figure 3) presents the basic wind speed map, which provides design 3-sec gust values at 33 ft in flat, open terrain. In the continental U.S., the wind speeds range from 90 mph to 150 mph. Since the wind pressure loads are a function of velocity squared, the most extreme design loads are $(150/90)^2$ = 2.8 greater than the areas with the lowest design winds. Thus, the design load criteria vary by nearly a factor of three. However, most hurricane prone areas typically have design values between 130-146 mph, and it might be reasonably generalized (by some) that the difference in design wind loads between such areas can be ignored.

The differences in the building codes in coastal states, however, are a major point of concern. Florida and the Carolinas have better construction practice because of the changes that resulted from Andrew, Hugo and other storms that have recently impacted the outer banks. Florida has the most stringent building code, which it maintains and updates on three year cycles. The rest of the country has either adopted the International Building Code (I-Code), an outdated version of the Standard Building Code, or uses no recognized code. The outcome is that generically describing the damage state of a residential building for all hurricane-prone areas is a poor predictive tool. For example, during Hurricane Rita in Texas it was observed that many older residential roof systems consisted of (a) 60 mph rated shingles, (b) 15 lb underlayment and (c) stapled sheathing. None of these building products are even allowed in Florida, much less together in one system.

Recommendation: Develop separate building damage states for (1) Florida and the Carolinas and (2) all other states.

3. General Comments on Wind Damage Descriptions

This section addresses individual components of the wind-damage descriptions:

Manufactured Housing

The performance of mobile homes is mentioned in every wind-damage description. First, "mobile home" is an outdated term. The industry term is manufactured housing. Correcting the terminology is perhaps not important. The general public is more familiar with "mobile homes" or "trailers." Second, the description of damage is fairly consistent with older (some pre-1994, all pre 1976) single-wide trailers. There are three eras of mobile home construction, pre-1976, 1977-1994, and post-1994. Prior to 1976, design guidelines were not in place. HUD created the first standard in the mid-1970s, which was improved in 1994. The current standard requires the mobile homes be built to the same loads at site-built structures. During Hurricane Charley, the newer homes did quite well and the older models did not. The photo in Figure 2 illustrates this point. The two homes are located on Bokeelia Island, and experienced the same wind speeds (no evidence of a tornado). The home in the background was only a few years old, and the home in the foreground was 30+ years old.

Figure 2. Mobile home damage in Hurricane Charley (2004)

Windows and Doors

In the U.S., nearly every residential window is only rated for water penetration resistance at 15% of the structure design pressure. Thus a window rated for 30 psf wind loading is deemed acceptable if it can hold out water at 4.5 psf. Recommendation: Include appropriate language that addresses water ingress (i.e. advise homeowners to engage in water management practices, such as putting towels next to window sills).

"Airborne" Debris

"Airborne" should be "Windborne" since the second term is more familiar (e.g., Windborne Debris Requirements are referenced by most building codes). In the 130-160 mph warning, the term "wind blown" is also used. One term should be used for consistency. Recommendation: use "windborne" to describe debris or projectiles carried by the wind.

Asphalt Shingle Roof Cover

Following Hurricane Charley, in areas where gust wind speeds were in the 130 to 140 mph range residential buildings with newly applied FBC (2007) approved shingles performed extremely well. While damage to roof covers can begin at gust wind speeds as low as 70 mph to 80 mph, this is certainly not the case with the new code shingles. Conversely, some new code shingles performed poorly in Hurricane Ike, suggesting that the performance varies with manufacturer, making general wind speed-damage correlations more difficult. Bottom line, the effect of age on the wind resistance of asphalt shingle roof coverings is not well understood. It should be conservatively assumed that shingle can become windborne in lower wind speeds.

4. Specific Comments on Wind Damage Descriptions

Notwithstanding our reservations in regard to the use of a generic wind damage scale, we generally accept the broad descriptions of damage as reflected in the draft SSHWS document and make the following additional suggestions:

Category One Hurricane (Sustained winds 74-95 mph [119-153 km/hr]). *Very dangerous winds will produce some damage.*
Windborne debris will cause some minor damage in areas with low-rise buildings. People struck by debris could be injured or possibly killed. Older (mainly pre-1976 construction) mobile homes could be severely damaged, overturned and uninhabitable. Newer mobile homes will sustain occasional damage involving the removal of roof covering and damage to carports. Some poorly constructed homes of frame construction will experience major damage, including roofs being lifted off and walls partially collapsing, leaving them uninhabitable. Homes with old and/or poorly maintained roofs could suffer extensive roof cover damage. Well constructed homes could have damage to shingles, siding, and gutters. Water intrusion through windows, doors and soffits is expected to occur in many homes. Windows will be susceptible to breaking if not properly covered. Some aluminum pool enclosures could fail. Partial roof failure could occur at some industrial parks, especially to those buildings with older light weight steel and aluminum coverings that were poorly maintained or inadequately attached. Some low rise apartment building roof coverings could be blown off. Glass windows in high rise buildings could fail from windborne debris from surrounding structures. Damage to commercial signage and fences will be common. Numerous large branches of trees will snap. Damage to power lines and poles will likely result in power outages that could last a few to several days. Hurricane Dolly (2008) is an example of a hurricane that brought Category 1 winds and impacts to South Padre Island, Texas.

Category Two Hurricane (Sustained winds 96-110 mph [154-177 km/hr]). *Extremely dangerous winds will cause substantial damage to poorly constructed buildings and structures.*
Structural collapse of some older (pre-1994) mobile homes and poorly constructed homes could cause severe injuries or possible death. People struck by windborne debris risk injury and possible death. Many older (pre-1976) mobile homes will be completely destroyed. Mobile homes built between 1976 and 1994 and homes of poor to average construction will be severely damaged, leaving some uninhabitable. Damage to well constructed homes is expected. A number of roofs and exterior walls will fail on poorly constructed buildings. Extensive damage to older shingle roof cover is expected. Loss of roof sheathing at gable ends and over porches is likely. Pool enclosure failures will be common. Minor glass damage will occur to residential structures. Frequent localized damage to metal roofs will occur to buildings at industrial parks. Partial roof and exterior wall failures are likely at low rise apartment buildings. Many windows in high rise buildings will be broken by windborne debris. Falling and broken glass will pose a significant danger even after the storm. Commercial signage and fences will be

damaged and often destroyed. Many trees will be snapped or uprooted and block numerous roads. Near total power loss is expected with outages that could last from several days to weeks. Potable water could become scarce as filtration systems begin to fail. Hurricane Frances (2004) is an example of a hurricane that brought Category 2 winds and impacts to coastal portions of Port St. Lucie, Florida with Category 1 conditions experienced elsewhere in the city.

Category Three Hurricane (Sustained winds 111-130 mph [178-209 km/hr]). *Extensive damage is expected!*
Collapse of some residential structures will put lives at risk. Airborne debris will cause extensive damage. People, pets, and livestock struck by the windborne debris will be injured or killed. Nearly all older (pre-1976) mobile homes will be destroyed. Nearly all older (pre-1994) mobile homes will be severely damaged. Older and/or poorly built homes will sustain severe damage with potential for complete roof failure and wall collapse. Most industrial buildings will suffer extensive cladding damage and those with unreinforced walls will be destroyed, with others experiencing partial roof and wall damage. Older low rise apartment buildings will be severely damaged or destroyed, and others will have partial roof and wall failure. Damage to all types of roof cover is expected, with the most extreme damage occurring on shingle roofs and older tile roofs. Numerous windows will be blown out of high rise buildings resulting in falling glass, which will pose a threat for days to weeks after the storm. Complete failure of older metal buildings is likely. Most commercial signage and fences are destroyed. Most trees will be snapped or uprooted. Electricity and water will be unavailable for several days to a few weeks after the storm passes. Hurricane Ivan (2004) is an example of a hurricane that brought Category 3 winds and impacts to coastal portions of Gulf Shores, Alabama with Category 2 conditions experienced elsewhere in this city.

Category Four Hurricane (Sustained winds 131-155 mph [210-249 km/hr]). *Devastating damage is expected!*
Collapse of residential structures will put lives at risk. Severe injury or death is likely for persons, pets, and livestock struck by windborne debris. Extensive damage to roof covers, windows, and doors will occur. Large amounts of windborne debris will be lofted into the air. Windborne debris damage will occur to many unprotected windows and some protected windows. Nearly all pre-1994 mobile homes will be completely destroyed. Mobile homes built after 1994 will suffer significant damage could be destroyed if not properly anchored, particularly if they have carports or additions. Older residential buildings will be destroyed due to window damage, roof sheathing failures, or whole roof blow off. Most homes will be damaged, with some total roof failure and wall collapse. Significant damage to wood roof commercial buildings occurs due to failure of roof sheathing. Some failures will occur to long span steel joist roof systems. Complete failures will occur of some older metal buildings. Unreinforced masonry walls often will fail. Nearly all industrial buildings and low rise apartment buildings will be severely damaged or destroyed. Large numbers of windows will be blown out of high rise buildings resulting in falling glass, which will pose a threat for days to weeks after

the storm. Considerable structural damage to large buildings is likely. Nearly all trees will be snapped or uprooted and power poles downed. Fallen trees and power poles will isolate residential areas. Power outages will last for weeks to possibly months. Long term water shortages will increase human suffering. Most of the area will be uninhabitable for weeks, perhaps longer. Hurricane Charley (2004) is an example of a hurricane that brought Category 4 winds and impacts to coastal portions of Punta Gorda, Florida with Category 3 conditions experienced elsewhere in the city.

Category Five Hurricane (Sustained winds greater than 155 mph [249 km/hr]). *Catastrophic damage will occur!*
Collapse of residential structures will put lives at risk. Severe injury or death is likely for persons, pets, and livestock struck by windborne debris. Extensive damage to roof covers, windows, and doors will occur. Large amounts of windborne debris will be lofted into the air. Windborne debris damage will occur to most unprotected windows and many protected windows. Likely all mobile homes will be completely destroyed. Older residential buildings will be destroyed due to window damage, roof sheathing failures, or whole roof blow off. Nearly all homes will be destroyed, with total roof failure and wall collapse. Significant damage to wood roof commercial buildings occurs due to failure of roof sheathing. Many failures will occur to long span steel joist roof systems. Complete failures will occur of many older metal buildings. Most unreinforced masonry walls will fail. Nearly all industrial buildings and low rise apartment buildings will be destroyed. Nearly all windows will be blown out of high rise buildings resulting in falling glass, which will pose a threat for days to weeks after the storm. Considerable structural damage to large buildings is likely with some complete failures possible. Nearly all trees will be snapped or uprooted and power poles downed. Fallen trees and power poles will isolate residential areas. Power outages will last for weeks to possibly months. Long term water shortages will increase human suffering. Most of the area will be uninhabitable for weeks, perhaps longer. Hurricane Andrew (1992) is an example of a hurricane that brought Category 5 winds and impacts to coastal portions of Cutler Ridge, Florida with Category 4 conditions experienced elsewhere in south Miami-Dade County.

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Appendix A. ASCE 7 Wind Map

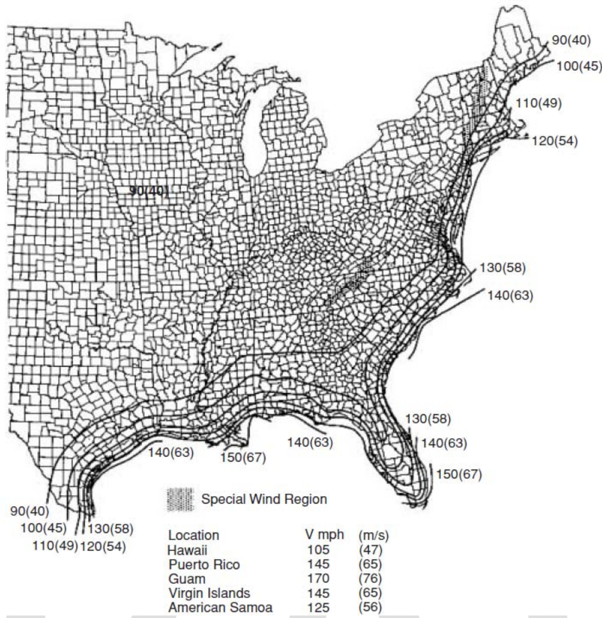

Figure 3. ASCE 7-05 (2006) Basic Wind Speed Map. Isotach values correspond to a 3-sec gust at 33 ft in open terrain.