



# EXPLORING

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## **Winds of Change: Resolving Roof Aggregate Blow-Off**

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## **ABSTRACT**

Designers, researchers, manufacturers, contractors, and building owners need to be aware of the recent code changes that affect gravel-surfaced built-up roofing (BUR) including their outright ban in high-wind areas. ARMA recently conducted research based on the Kind-Wardlaw wind tunnel research and design method, which demonstrates that gravel-surfaced roofing systems are viable options in high-wind areas with appropriate use of aggregate size and parapet heights. Attendees will learn where gravel BUR systems are allowed by the state/local/municipal codes and the specification and installation techniques suggested or required by those codes.

## **SPEAKERS**

**Jay Crandell** has over 20 years of experience in building code and standards development, building technology research, construction, and design. He has conducted scientific studies of building performance in major natural disasters such as Hurricanes Andrew, Opal, Charley, and Katrina. He has led major laboratory testing and field-monitoring efforts to understand and improve methods of building design and construction. He is active in various professional organizations/committees such as ASCE 7, building loads; ASCE 32, FPSF foundations; ICC-Ad Hoc Committee on Wall Bracing; Wood Design Standards Committee; and Committee on [Steel] Framing Standards.

**Mike Fischer** is director of codes and standards for the Asphalt Roofing Manufacturers Association (ARMA). He has over 25 years of experience with energy codes, product standards, regulatory affairs, and building product safety issues. He is a member of the International Code Council (ICC), the ICC Industry Advisory Committee, and the American Society for Testing and Materials (ASTM). Fischer has worked with agencies such as the U.S. Department of Energy, the Florida Building Commission, Texas Department of Insurance, and the North Carolina Department of Insurance.

# Winds of Change: Resolving Roof Aggregate Blow-Off

## ABSTRACT

Designers, researchers, manufacturers, contractors, and building owners need to be aware of the recent code changes that limit gravel-surfaced built-up roofing (BUR), including their outright ban in hurricane-prone regions. In response to these code changes, the Asphalt Roofing Manufacturers Association (ARMA) recently conducted research based on the Kind-Wardlaw (K-W) wind-tunnel studies (Kind, 1977) and design method (Kind and Wardlaw, 1976). Results demonstrate that the use of aggregate-surfaced roofing systems is a viable option in high-wind areas with appropriate aggregate sizing and parapet design. This paper provides a review and analysis of current building-code requirements for aggregate-surfaced BUR systems. Next, an evaluation of the K-W design method, which resulted in the development of a simplified and improved (modified) K-W design method for control of roof aggregate blow-off, is presented. Also addressed are recommended (proposed) building-code requirements for aggregate sizing and parapet heights to control aggregate blow-off based on the modified K-W design method.

## INTRODUCTION

Concern with roof aggregate blow-off is not new (Minor, 1977; Smith *et al.*, 1992). It has continued to be reinforced by field observations, particularly in regard to damage caused to glazing on surrounding buildings as well as the building from which the aggregate was lifted into the airstream. *Figure 1* shows characteristic damage from roof aggregate impacts



**Figure 1 – Characteristic aggregate or small projectile impact damage to glazing in a wind-borne debris region on Hancock Bank Building, Gulfport, MS, caused by Hurricane Katrina (photo by M. Fischer).**

to glazing, including some potential damage from other causes (e.g., wind pressure) (NIST, 2006). Unfortunately, many similar field observations fail to report other important factors contributing to glazing damage. For example, many existing buildings (like the one shown in *Figure 1*) do not have glazing in compliance with modern standards and code requirements for impact resistance (required in wind-borne debris regions) or, more generally, wind pressure resistance. Glazing that is not compliant with

either one of these relatively new criteria can exacerbate glazing damage in high-wind events such as might more fully explain the nature and extent of glazing damage shown on the building in *Figure 1*. Conversely, buildings with glazing compliant with modern requirements might be expected to perform as shown in *Figure 2*, with little or no glazing damage from wind pressure or wind-borne debris. For additional information on these and other similar observations, refer to Fischer (2005 and 2006).



**Figure 2 – Characteristic successful performance of code-compliant glazing (wind pressure-rated and impact-resistant) on Island View Casino Resort, Gulfport, MS, during Hurricane Katrina (photo by M. Fischer).**

Because glazing damage results in increased wind load on a building structure and its components due to internal pressurization (or depressurization) as well as extensive water damage to building contents in hurricane events, it is important to have a balanced and rational approach to control this type of building damage. Such a rational approach must consider all relevant factors in the context of the following two mitigation concepts:

- Reduce hazard (i.e., alter, control, or eliminate the source of hazard).
- Decrease vulnerability (i.e., improve resistance to hazard).

It is not anticipated that hurricanes themselves can be practically altered, reduced, or controlled in their impact in the foreseeable future. Thus, it has been common practice to focus on decreasing vulnerability. Decreased vulnerability is achieved through various preparedness actions and building-code requirements such as minimum requirements for wind pressure resistance and impact resistance of glazing. These actions are also able to reduce or control the hazard source itself, such as sources of wind-borne debris hazard.

For example, the 2007 Florida Building Code (FBC) contains provisions for resistance to wind and wind-

borne debris specific to the high-velocity hurricane zone (or HVHZ, defined in the FBC as Broward and Dade Counties), that extend beyond buildings themselves to include fences, utility sheds, and screen enclosures not addressed in the IBC ([www.floridabuilding.org](http://www.floridabuilding.org), 9/3/09). Other jurisdictions recognize that in addition to building products such as roof gravel, clay and concrete tiles, and other materials, there are myriad sources of debris that can cause damage during storm events. Tree limbs, barbecue grills, and lawn furniture are among the items recommended to be secured before storm events by jurisdictions such as the state of Louisiana ([www.ohsep.louisiana.gov](http://www.ohsep.louisiana.gov)

/factsheets/Trees&WindborneDebris.htm, 9/3/09).

As an extreme example of actions taken to reduce windborne debris hazard, roof gravel was completely banned from use in broadly defined hurricane-prone regions in the 2006 IBC as discussed later in Part 1 of this paper. However, a more rational approach should rely on sound scientific principles and engineering to design the roof aggregate and the roof system to prevent (resist) aggregate blow-off. In fact, aggregate-surfaced roofs can be designed (not banned) as an effective means of controlling the hazard caused by roof aggregate admitted into the wind field as projectiles (see Parts 2 and 3 of this paper). In the same manner, other structural and cladding components on buildings are also designed to resist wind load such that the building performs acceptably and building parts are unlikely to become a projectile hazard to downstream structures.

As shown in *Figure 3*, most problems with glazing damage linked to debris from aggregate-surfaced roofs have been associated with extreme wind events such as hurricanes (predominantly limited to wind-borne debris regions) and have involved roofs not in compliance with ANSI/SPRI RP-4, Wind Design Standard for Ballasted Single-Ply Roofing Systems, (RP-4) standard (SPRI, 2008) and with aggregate-surfaced, built-up roofs (BUR) and sprayed polyurethane foam (SPF) roofs, which the RP4 standard was not intended to address. For the purposes of this paper, aggregate is inclusive of crushed rock, gravel, and stone used as ballast or protective surfacing on low-slope roofing systems.

As a result of the above concern, recent building-code changes (e.g., IBC 2006) severely restricted the use of aggregate-surfaced BUR and SPF roofs. Yet, these new provisions were not based on the K-W design method (Kind Wardlaw, 1976), the wind tunnel studies underlying the K-W design method (Kind, 1977), or a quantitative



**Figure 3 – Aggregate scour and blow-off from a “noncompliant” aggregate-surfaced roof in Hurricane Katrina in 2005 (photo from FEMA 549).**

analysis of observed “good” and “bad” roofing system performances in real wind events. Instead, current building-code limitations are based on variation in surface pressure with building height, which is known to be an inappropriate predictor of aggregate blow-off or scour due to pressure equalization effects (Smith, 1997). Furthermore, these recent restrictions do not address critical parameters such as aggregate size and parapet height, which govern performance.

The authors’ objectives for this paper are twofold:

- (1) Address the above-described concerns in a more rational manner to ensure acceptable aggregate-surfaced roof-system performance in high-wind events, and
- (2) Provide a balanced, performance-based solution to replace an outright ban of aggregate-surfaced BUR and spray polyurethane roof systems in hurricane-prone regions, as was initiated in the

2006 IBC and continued in the 2009 IBC.

To address these objectives, this paper is organized in the following three parts:

- Part 1 – Review and analysis of current building-code provisions,
- Part 2 – Performance-based design method for prevention of roof aggregate blow-off.
- Part 3 – Recommended prescriptive code requirements to prevent roof aggregate blow-off.

## **PART 1: REVIEW AND ANALYSIS OF CURRENT BUILDING CODE REQUIREMENTS**

### **Background**

A thorough review of the International Code Council, Inc. (ICC) code proposal submittals and resulting code changes leading up to a recent ban on use of aggregate-surfaced roofs in hurricane-prone regions must necessarily include con-

sideration of the landscape within the code arena at the time these changes occurred. This background section is intended to provide useful context to the discussions on specific code requirements, which follow later.

First, the development of U.S. model building codes generally occurs outside of a governmental process. While state and local codes are enacted into law by statute or ordinance, often including a modest number of local amendments, the model language that forms the basis for such codes is the result of a series of committee hearings, public comment processes, and a final “general assembly” consideration by vote of only governmental members of ICC. In addition, rules limit the type and length of testimony allowed, which preclude the use of any type of audiovisual materials or graphics (except as included in published code hearing materials). These procedures are necessary to provide a means of processing a sometimes formidable number of proposals in a reasonable amount of hearing time. However, just as in the building construction process, quantity and quality are not always compatible and are difficult to balance for optimal outcome. While state and local code adoption processes do provide some opportunity for a “check-and-balance,” in most cases, technical code provisions are adopted with little or no additional consideration. Because of this regulatory “inertia” resulting from the model code development process itself, stakeholders’ interests are best served in the long run by promoting sound technical positions within the model code development arena.

Second, damage to structures and the resultant loss of life and property from tropical storms and hurricanes provides for legitimate and often passionate debate on construction codes issues. With the issues surrounding the use of aggregate as a surfacing for roof systems in high-wind regions, the hurricane seasons between 2004 and 2005 provided an interesting backdrop for the code development process that brought a severe limitation

on the use of rooftop gravel to the ICC process.

Code proposals for the 2004-2005 ICC code development cycle were due on August 20, 2004, just one week after Hurricane Charley made landfall on Florida’s west coast at Punta Gorda. The final action hearings for the code proposals to the 2006 IBC began on September 29, 2005, exactly one month after Hurricane Katrina devastated New Orleans and surrounding areas of the U.S. gulf coast. It is with the tremendous damage resulting from these and other storms, including Dennis, Rita, and Ivan fresh in mind that the ICC code development committees and final action assemblies determined the outcome of an IBC structural code proposal aimed at limiting the use of rooftop gravel (actually banning it completely in hurricane-prone areas, including extensions well inland to a 90-mph design wind speed).

**IBC 2006**

In the context of the previous discussion, the following new requirement banning the use of aggregate-surfaced roofs in hurricane-prone regions was included in the 2006 IBC:

**“1504.8 Gravel and stone.** Gravel or stone

shall not be used on the roof of a building located in a hurricane-prone region...”

In addition, *Table 4* was adopted to limit building height in all other wind regions of the U.S., including the least hazardous, when aggregate-surfaced roof systems are used.

The code language above resulted from a submitted code proposal, S1-03/04 (S1), to the IBC Structural Committee for consideration and inclusion in the 2004 IBC Supplement. S1 included a ban on the use of any gravel and stone in any hurricane-prone region, as well as a building height limitation on use of gravel and stone on roofs in other areas. The building height limitation varies depending upon the basic wind speed and exposure category for the specific building site. Supporting information for the proposal indicates that the intent is to prevent glass breakage, internal pressurization, and subsequent building damage when rooftop gravel or stone becomes wind-borne debris during high-wind events. For reasons mentioned in the introduction to this paper, these are all worthy goals.

However, as a matter of hindsight, this proposal (including its reason

<b>Table 1504.8</b>			
<b>Maximum Allowable Mean Roof Height Permitted for Buildings With Gravel or Stone on the Roof in Areas Outside a Hurricane-Prone Region</b>			
<b>Basic Wind Speed From Figure 1609 (mph)</b>	<b>Maximum Mean Roof Height (ft)</b>		
	<b>Exposure Category</b>		
	<b>B</b>	<b>C</b>	<b>D</b>
85	170	60	30
90	110	35	15
95	75	20	NP
100	55	15	NP
105	40	NP	NP
110	30	NP	NP
115	20	NP	NP
120	15	NP	NP
Greater than 120	NP	NP	NP

**Figure 4 – Table 1504.8 from the 2006 IBC. (NP = gravel and stone not permitted for any roof height.)**

statement and the resulting code requirements in the 2006 IBC) raises the following four concerns:

1. The overall proposal ignores key roof design variables, such as aggregate size and parapet height, which govern roof performance and prevention of roof gravel blow-off as reported in the literature (Kind-Wardlaw, 1976; Kind, 1977; SPRI, 2008; etc.).
2. Although a mathematically creative approach, the building height limitations in Table 1504.8 (Figure 4) were based on an assumption that, in contradiction to the literature (Smith, 1997), wind velocity pressure can be used as an effective means for controlling or predicting roof gravel blow-off. In addition, a further unproven assumption postulates that the “critical velocity pressure” at which blow-off begins to occur is associated with a 120-mph, exposure-B wind condition near to the ground.
3. The field observations from recent hurricane events presented as a basis for the change proposal were related to severe wind conditions experienced within the “wind-borne debris region.” But, as an unintended consequence of #2 above, the proposal essentially extended or extrapolated this direct experience to justify a complete ban of roof aggregate in a much broader (lower-hazard) wind condition encompassing areas extending well inland, yet still within the more broadly defined “hurricane-prone region.” Implications with regard to these code-defined wind regions are discussed in a later section.
4. Lastly, the inclusion of wind speeds up to 120 mph in Table 1504.8 (Figure 4) ap-

pears inconsistent and lends confusion to why roof gravel might be used in a nonhurricane-prone 120-mph wind region, yet not in a hurricane-prone, 120-mph or lesser wind region.

Apparently, the above four concerns were not fully understood at the time of the hearing or were considered inconsequential in view of a perceived sense of urgency to take action for reasons discussed previously by way of background to this part of the paper. In comparison to an improved technical approach (see Part 2) and recommended code requirements (see Part 3), the IBC 2006 provisions carry two significant impacts:

1. The “ban” instituted in hurricane-prone regions is overly conservative and unjustified, and
2. The building height limitations in Table 1504.8 (Figure 4) are not conservative in that they do not require or address minimum parapet heights to ensure retention of roof aggregate of any size.

### IBC 2009

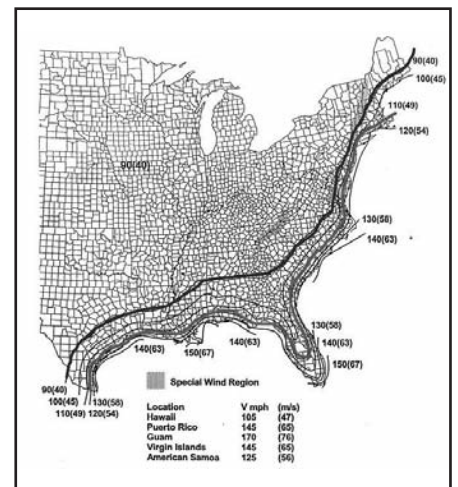
During the development of the 2009 IBC, the limitations on the use of stone and gravel on roofs were modified to exclude single-ply systems that comply with ANSI/SPRI RP-4 (SPRI, 2008). The technical study that led to the creation and code adoption of the ANSI/SPRI standard are discussed briefly in Part 2 of this paper. ARMA and other stakeholders submitted proposals to modify and/or remove the prohibition of gravel and stone in hurricane-prone regions; but, absent clearly better technical justification than used for the 2006 IBC provision or a similar product performance standard to RP-4, industry representatives were essentially attempting to disprove a negative, and the effort failed.

Thus, the provisions in the 2009 IBC remain the same as those in the 2006 IBC discussed previously.

### Hurricane-Prone vs. Wind-borne Debris Regions

The “hurricane-prone” region is defined as the U.S. Atlantic and Gulf of Mexico coastal areas, with a basic wind speed greater than 90 mph. The code further defines the “wind-borne debris region” as a subset of the hurricane-prone region where the basic wind speed is greater than 120 mph or is greater than 110 mph and also within one mile from the coastal mean high-water line. Figure 5 shows the ASCE-7 hurricane-prone region between the coast and the blue line indicating 90-mph basic wind speed, and the smaller wind-borne debris region identified by the red line. Figure 5 – Illustration of hurricane-prone region (seaward from blue line) and wind-borne debris regions (seaward from red line). (Image: Lorraine Ross, Intech Consulting.)

The designation of specific geographical areas as wind-borne debris regions is founded on wind engineering judgment, with a consideration of actual hurricane and tropical storm wind data and varied experiences with building performance during storm events. The subjective and controversial delineation of 120-mph



**Figure 5 – Illustration of hurricane-prone region (seaward from darker line) and wind-borne debris regions (seaward from lighter line). Image by Lorraine Ross, Intech Consulting.**

basic wind speed as the threshold for glazed opening protection against wind-borne debris is outside of the scope of this paper, but the authors wish to point out the inconsistency of requirements that purport to prevent certain building products, like roof gravel, from becoming wind-borne debris (by eliminating its use), while at the same time not requiring protection of glazed openings from other sources of debris within the broader hurricane-prone region beyond the limits of the wind-borne debris region. Furthermore, previously discussed

IBC requirements ban roof gravel within the hurricane-prone region in such cities as Hartford, Philadelphia, Newark, New York City, San Antonio, Tuscaloosa, Macon, Augusta, and Raleigh, despite the lack of storm data suggesting that aggregate-surfaced roofs have resulted in wind debris fields and damaged buildings in these areas.

The FEMA 490 2004 U.S. hurricane season report recommended that roofing manufacturers work with government officials to develop and codify technically based criteria for

aggregate surfaces on built-up and sprayed polyurethane foam roofs (FEMA, 2005). After Katrina, FEMA issued report 548, which included a recommendation that existing critical and essential facilities replace aggregate-surfaced roofing with nonaggregate surfaces (FEMA, 2006). The report also recommended that these facilities, if located in the ASCE-7 wind-borne debris region, protect glazed openings by the use of shutters, films, or laminated glazing. It is important to note that during the FEMA Katrina field observations leading to these recommendations, Mitigation Assessment Teams (MAT) were deployed entirely within counties located within the wind-borne debris region and not more broadly in the hurricane-prone region extending further inland (see Figure 6).

**PART 2: PERFORMANCE-BASED DESIGN METHOD FOR PREVENTION OF ROOF AGGREGATE BLOW-OFF**

**Background**

The Kind-Wardlaw design method (“K-W” design method) for prevention of scour and blow-off of aggregate from aggregate-surfaced roofs has been available since the 1970s (Kind & Wardlaw, 1976). It saw limited use until the 1980s, when adopted as the basis for the initial 1988 edition of RP-4 standard which, in its updated form, continues to be used by the single-ply roofing industry for ballasted roofs (SPRI, 2008). SPRI utilized the K-W design method as the basis for aggregate-ballasted roof systems to prevent ballast scour.

For aggregate-surfaced BUR and SPF roof systems, a main wind-related issue of concern is aggregate blow-off. Scour is not considered important to BUR and SPF roofs, except to the extent that it might require maintenance (redistribution of aggregate) after an extreme wind event to maintain fire resistance and the long-term durability of the roof system against degradation caused by solar (UV) radiation. Therefore, the K-W design method was evaluated and modified

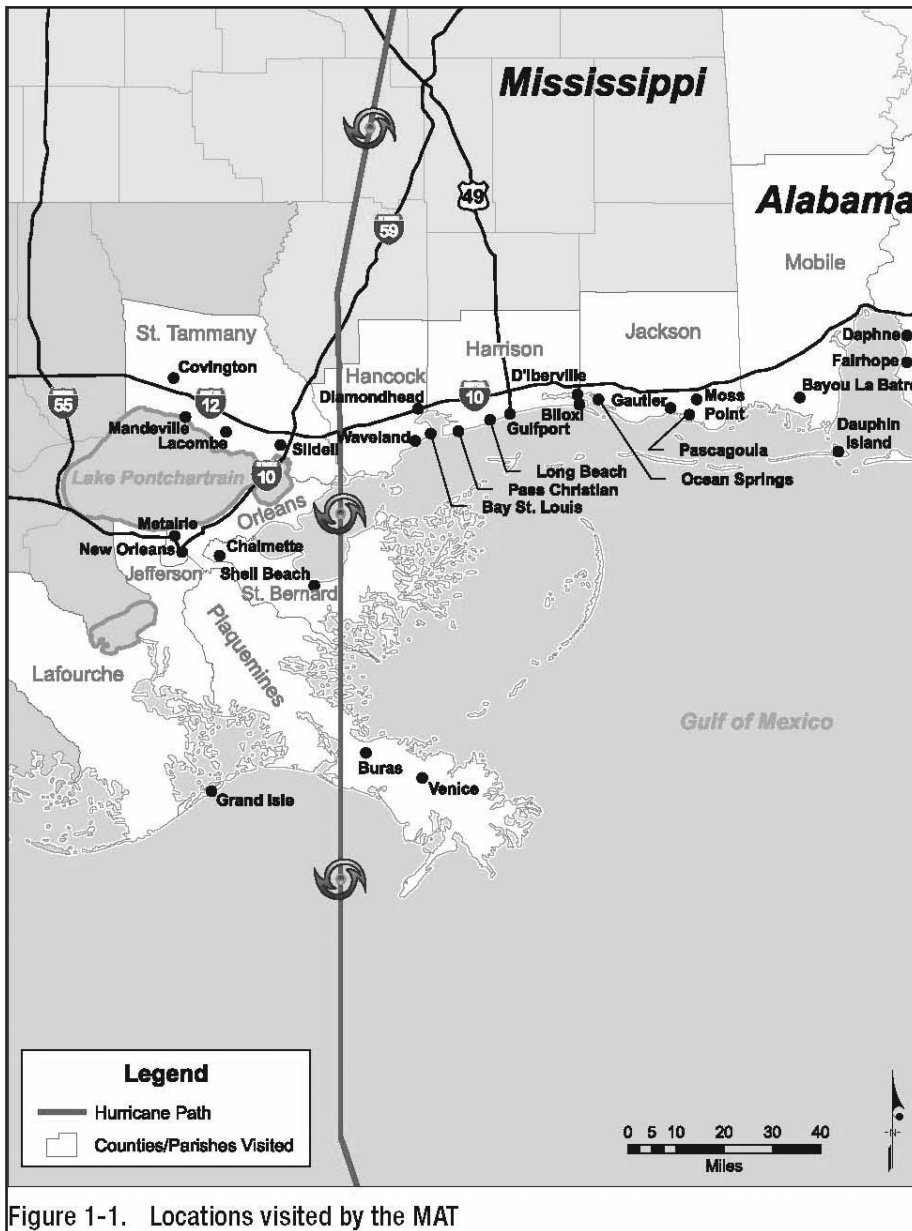


Figure 1-1. Locations visited by the MAT

Figure 6 – FEMA MAT team deployments within windborne debris region only following Hurricane Katrina.

with a focus on developing an improved design method to control or limit aggregate blow-off from aggregate-surfaced BUR and SPF roof systems, resulting in the modified K-W design method discussed in the next section. The derivation of the modified K-W design method is addressed elsewhere in the literature (Crandell and Smith, 2009). It included a careful re-evaluation of the Kind (1977) wind-tunnel data and the K-W design methodology (Kind-Wardlaw, 1976), in addition to a verification with and calibration to quantitative field observations of aggregate-surfaced roof performance in major hurricanes.

### Modified K-W Design Method

Based on the evaluation discussed by way of background in the previous section, the modified K-W design method for prevention of aggregate blow-off from aggregate surfaced BUR and SPF roof systems is presented as follows:

**STEP 1:** Determine mapped basic (design) wind speed (mph, gust) for standard conditions (33-ft elevation and flat, open terrain – Exposure C) using the ASCE 7-05 wind map (ASCE 2005).

**STEP 2:** Adjust mapped wind speed (Step 1) to a design wind speed at roof height using the following equation and terrain roughness parameters:

$$V_{\text{roof}} = \left\{ \frac{h}{h_g} \right\}^{(1/\alpha)} \left\{ \frac{33}{900} \right\}^{(1/9.5)} \times V_{\text{map}} \times I \times K_d$$

$$= 1.4 \times \left\{ \frac{h}{h_g} \right\}^{(1/\alpha)} \times V_{\text{map}} \times I \times K_d$$

where:

$V_{\text{roof}}$  = gust wind speed at roof height (mph)

$V_{\text{map}}$  = gust wind speed from ASCE 7 wind map (mph)

$I$  = building importance factor (use 0.75 for Category I buildings; 1.0 for Category II; and 1.1 for Categories III & IV)\*

$h$  = building roof height (ft)

$h_g$  = gradient height for site wind exposure (Exp B, use 1270 ft; Exp C, use 900 ft; Exp D, use 700 ft)\*\*

$\alpha$  = power law terrain roughness parameter (Exp B – 6.2; Exp C – 9.5; Exp D – 11.5)\*\*

$K_d$  = 0.9 = wind speed directionality factor consistent with ASCE 7 wind load directionality factor

\*Note: importance factors per ASCE 7-05 have been modified to apply to wind speed in lieu of wind load

\*\*Note: parameters for Exposure B are based on “typical” values per ASCE 7 commentary)

**STEP 3:** Determine critical (blow-off) wind speed for roof system design as follows:

$$V_{\text{cr}} = 20.8 (H) + 60$$

where,

$V_{\text{cr}}$  = critical wind speed (mph, gust)

$H$  = parapet height above roof surface (feet)

**STEP 4:** Adjust critical wind speed (Step 3) for aggregate size when different than 1-in nominal diameter as follows:

$$V_{\text{cr}}' = V_{\text{cr}} \times (d)^{1/3}$$

where,

$V_{\text{cr}}'$  = aggregate size-adjusted critical wind speed (mph, gust)

$d$  = aggregate nominal diameter (inches)

(Nominal aggregate diameter is based on mean aggregate size – see examples below)

- ASTM D1863 #7 .....  $d = 3/8$  in\*
- ASTM D1863 #67 .....  $d = 3/8$  in
- ASTM D1863 #6 .....  $d = 1/2$  in
- ASTM D448 #4 .....  $d = 1$  in\*\*
- ASTM D448 #24 .....  $d = 1 1/2$  in\*\*
- ASTM D448 #2 .....  $d = 2$  in\*\*

\*ASTM D1863 #7 aggregate has a mean aggregate size similar to #67 aggregate, but with a maximum aggregate size of 1/2 in instead of 3/4 in.

\*\*ASTM D448 aggregate is not typically specified for BUR and SPF roof systems

**STEP 5:** Verify that  $V_{\text{roof}} \leq (1.1 \times V_{\text{cr}}')$  (NOTE: The 1.1 factor is a calibration factor discussed briefly in the background section and explained completely in Crandell and Smith [2009]).

If the above design check is not satisfied, increase aggregate size or parapet height and reevaluate starting at Step 3.

## PART 3 – RECOMMENDED PRESCRIPTIVE CODE REQUIREMENTS TO PREVENT ROOF AGGREGATE BLOW-OFF

Based on the modified K-W design method presented in the previous sec-

tion, Table 1 presents minimum parapet height requirements based on aggregate nominal diameter (in), building roof height (ft), mapped design wind speed (mph, gust), and site wind exposure (B, C, or D). An identical table was submitted for consideration in the development of the 2012 IBC ([www.iccsafe.org](http://www.iccsafe.org)). Additional limitations in the IBC 2012 proposal include:

- In a hurricane-prone region, aggregate is not permitted on Occupancy Category III or IV buildings when the basic wind speed is greater than 100 mph.
- In a hurricane-prone region, aggregate is not permitted on Occupancy Category I or II buildings when the basic wind speed is greater than 110 mph.

The requirements in Table 1 are considered to be adequate and universally applicable. However, judgment should still be exercised in the use of these requirements. For example, the requirements of Table 1 do not explicitly account for the following additional considerations that could justify increasing or decreasing the calculated parapet heights:

- Topographic wind speed-up effects that could increase roof-level wind speeds
- Wind shielding due to trees and surrounding wind obstructions in suburban or wooded settings that would reduce roof-level wind speeds for low-rise buildings that are generally no taller than the height of surrounding obstructions to wind.
- Potential channeling and wind speed-up in dense urban areas
- Use of a floodcoat that embeds all aggregate (“double-surfacing”) or pavers at roof corners that would tend to

Minimum Required Parapet Height (in) for Aggregate-Surfaced Roof Coverings <sup>a,b</sup> for Occupancy Category 1 and Category II Buildings <sup>c</sup>																
ASTM D1863 Gradation	Mean Roof Height <sup>d</sup> (ft)	WIND EXPOSURE AND BASIC WIND SPEED (MPH, GUST) <sup>e</sup>														
		Exposure Category B					Exposure Category C					Exposure Category D				
		85	90	100	110	120	85	90	100	110	120	85	90	100	110	120
No. 7 or No. 67	15	0	0	15	20	25	22	25	31	38	45	27	31	38	45	53
	20	0	12	17	23	28	23	27	33	40	47	29	32	40	47	55
	30	13	25	21	27	32	26	29	36	44	51	31	35	43	50	58
	40	15	18	24	29	35	28	31	39	46	53	33	37	45	52	60
	50	17	20	26	32	38	29	33	40	48	55	34	38	46	54	62
	60	18	21	28	34	40	30	34	42	49	57	35	39	47	56	64
	80	21	24	30	37	43	32	36	44	52	60	37	41	49	58	66
	100	23	26	33	40	46	34	38	46	54	62	38	43	51	60	68
	125	25	28	35	42	49	36	40	48	56	64	40	44	53	62	70
150	27	30	37	45	52	37	41	50	58	66	41	45	54	63	72	
No. 6	15	0	0	11	15	20	16	19	25	31	37	22	25	31	38	45
	20	0	0	13	17	22	18	21	27	34	40	23	26	33	40	47
	30	0	11	16	21	26	20	24	30	36	43	25	29	36	43	50
	40	0	13	18	24	29	22	25	32	39	45	27	30	37	45	52
	50	12	15	20	26	31	23	27	34	40	47	28	31	39	46	53
	60	13	16	22	28	33	24	28	35	42	49	29	33	40	47	55
	80	16	19	25	30	36	26	30	37	44	51	30	34	42	50	57
	100	18	21	27	33	39	28	31	39	46	53	32	36	43	51	59
	125	19	23	29	35	42	29	33	40	48	55	33	37	45	53	61
150	21	24	31	37	44	30	34	42	50	57	34	38	46	54	62	

SI: 1 in = 25.4 mm, 1 ft = 0.3 m, 1 mph = 0.44 m/s

a. Interpolation between wind speeds and building heights shall be permitted.

b. Aggregate-surfaced roofs shall not be permitted for wind speeds greater than 120 mph.

c. For occupancy Category III and IV buildings, use the next higher wind speed column.

d. Mean roof height shall be measured from the grade plane to the roof surface at the perimeter of the roof portion under consideration.

e. Wind exposure and basic wind speed shall be determined in accordance with ASCE 7-05.

**Table 1**

reduce vulnerability to aggregate blow-off in lieu of using larger aggregate sizes or parapet heights.

## CONCLUSIONS & RECOMMENDATIONS

- Aggregate used as surfacing for improperly designed low-slope roof systems has been cited as a cause of damage to structures, primarily in wind-borne debris regions and as a result of hurricane events. The breakage of unprotected or noncode-compliant glass caused by wind pressure and
- wind-borne debris (including roof aggregate) during such events can result in pressurization of buildings, lead to additional damage from wind-driven rain, and contribute to structure failure.
- As addressed in Part 1 of this paper, regulations currently governing the use of aggregate on roofing systems are based on faulty technical reasons or assumptions and should be replaced or improved with better solutions that address important variables, including design
- wind speed at roof height, aggregate size, parapet height, and building use.
- As addressed in Part 2 of this paper, an improved design method to prevent roof-aggregate blow-off has been evaluated, verified, and presented as a means to address the need for a balanced and rational approach for the design of BUR and spray polyurethane roof systems.
- In Part 3 of this paper, simple prescriptive building-code requirements are recommend-

ed and available for use based on the design method presented in Part 2 of this paper.

## REFERENCES

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