Wind-Borne Debris Hazards

Subcommittee on Wind-Borne Debris

Edited by Nigel Berkeley Kaye, Ph.D.

ASCE

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Task Committee on Wind-Borne Debris

The Task Committee on Wind-Borne Debris was established by the Environmental Wind Engineering Committee of the ASCE Wind Engineering Division (WED). The goal of the committee was to produce a review of the current state of knowledge on issues related to risk from wind-borne debris from severe wind storms. The committee members worked with an international team of authors and reviewers to produce this state-of-the-art report on wind-borne debris hazards. The final peer reviewed document was approved by the Executive Committee of the WED on April 5, 2017.

Task Committee Members:
Nigel Berkeley Kaye, *Chair and Editor*
Gregory Alan Kopp, *Co-Editor*
Christopher William Letchford
Weichiang Pang
David Otway Prevatt
Douglas Alexander Smith

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Nomenclature

A	Debris cross-sectional area
A_e	Critical condition coefficient
A_p	Paver area
$\vec{a}$	Acceleration vector
C_a	Empirical asymptotic debris speed coefficient
C_D	Drag coefficient
C_f	Force coefficient
C_L	Lift coefficient
C_m	Moment coefficient
C_p	Pressure coefficient
C_{pB}	Pressure coefficient on base of paver
C_{pT}	Pressure coefficient on top of paver
C_z	Net uplift coefficient
C_1	Asymptotic debris speed coefficient
d	Debris diameter or smallest dimension of non-compact debris
d_p	Particle diameter
d_*	Dimensionless particle diameter
DC_p	Uplift differential pressure coefficient
F_D	Drag force
F_L	Lift force
F_R	Resisting force
$\vec{F}$	Force vector
Fr	Froude number
g	Gravitational acceleration
h	Parapet height
I	Mass moment of inertia
K	Tachikawa number
K_c	Critical Tachikawa number
L	Longest debris dimension
L_B	Building length
l_f	Full-scale dimension
l_l	Laboratory-scale dimension
M	Moment
m	Debris mass
p	Pressure
Re	Reynolds number based on the skin friction velocity
t	Time

$\bar{t}$	Non-dimensional time
U	Horizontal wind speed
U_c	Velocity required to initiate flight
U_{eave}	Eave height wind speed
U_f	Full-scale wind speed
U_H	Mean wind speed at the mean roof height
U_l	Laboratory-scale wind speed
U_r	Reference velocity
u_*	Skin friction velocity
u_{*_c}	Critical skin friction velocity
$\hat{u}_H$	3 second gust speed at the mean roof height
u_{rel}	Horizontal component of relative wind speed
V	Vertical wind speed
V_I	Debris impact velocity
V_R	Local 0.2 second gust speed at 10 m over flat terrain
V_{rel}	Relative wind speed
v_{rel}	Vertical component of relative wind speed
W	Plate width
x	Horizontal coordinate
$\vec{x}$	Displacement vector
$\bar{x}$	Non-dimensional horizontal coordinate
z	Vertical coordinate
$\bar{z}$	Non-dimensional vertical coordinate
α	Initial launch angle
β	Angle between drag force and the horizontal coordinate
Δ	Square of the ratio of debris length to radius of gyration
θ	Angle of debris axis to the horizontal
ξ	Angle of attack
ρ_a	Density of air
ρ_f	Fluid density
ρ_p	Particle density
ρ_{pf}	Full-scale debris density
ρ_{pl}	Laboratory-scale debris density
ρ_w	Density of water
τ_c	Critical surface shear stress
τ_0	Surface shear stress
υ	Kinematic viscosity
ϕ	Product of the lift coefficient and Tachikawa number

CHAPTER 1

Introduction

Nigel Berkeley Kaye*

1.1 THE PROBLEM OF WIND-BORNE DEBRIS

Wind-borne debris in severe storms is a major hazard to people and structures. There is extensive literature on the damage to structures from wind-borne debris during hurricanes (e.g., Kareem and Bashor 2006) and tornadoes (e.g., Kuligowski et al. 2013). The mechanics of wind-borne debris is a complex problem involving motion initiation, flight through a heterogeneous unsteady wind field, impact, and resulting damage. In order to quantify the risk from wind-borne debris damage to a given structure one needs to understand potential sources of debris (e.g., tree limbs, roof aggregate, building components), the conditions under which they become wind-borne (e.g., limb breakoff, roof aggregate blow-off, building component failure), the flight trajectory (which depends on the release mechanism and the debris geometry), the energy and momentum at impact, and the ability of a structure to resist that impact. Much is known about each of these processes, although there is also considerable uncertainty about many of the key parameters. The prediction of the risk of wind-borne debris damage to a particular structure is hard to quantify.

There are standards for what portions of a building must be impact resistant for different wind climate regions. However, there is still much debate about the appropriate method for establishing these regions, the appropriate quantification of risk, and the resulting design response. This debate is clearly recognized in the commentary on enclosure classification, C26-10 of ASCE 7-10 (ASCE 2010), where the authors' state:

> The committee recognizes that there are vastly differing opinions, even within the standards committee, regarding the significance of these parameters that are not fully considered in developing standardized debris regions or referenced impact criteria.

Despite this ongoing uncertainty, significant research progress has been made in our understanding of all aspects of the wind-borne debris problem in recent years. The goal of this book is to provide a concise summary of our current state of knowledge on all aspects of the wind-borne debris problem along with detailed

*Glenn Department of Civil Engineering, Clemson University, Clemson, SC, USA.