THE MECHANICS OF FLYING DEBRIS IN SEVERE WIND STORMS

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Introduction

The Shelter Building Program of the Department of Public Works of Queensland is intended to identify and upgrade existing buildings in the cyclone belt to provide shelter during the event of a severe tropical cyclone. Resistance to flying debris is an important consideration during severe cyclones. Penetration of the building envelope by flying missiles has a number of undesirable results : high internal pressures threatening the building structure, wind and rain penetration of the inside of the building, the generation of additional flying debris, and the possibility of flying missiles inside the building endangering the occupants.

This paper addresses the mechanics of flying debris. Previous work on the analysis of the initiation of flight, and of the trajectories of missiles is reviewed. A new analysis of flight times and distance travelled is given.

Analysis of flight initiation

Wills et al [1], have provided the most useful analysis to date of debris flight conditions. They considered 'compact' objects, sheet objects, and rods and poles, and established relationships between the body dimensions, and the wind speed, U_f, at which flight occurs and the objects become missiles. For each the three categories, these relationships are :

$$\ell = \frac{\frac{1}{2}\rho_a U_f^2 C_F}{I\rho_m g} \quad (1)$$

$$t = \frac{\frac{1}{2}\rho_a U_f^2 C_F}{I\rho_m g} \quad (2)$$

$$d = \frac{\frac{2}{\pi}\rho_a U_f^2 C_F}{I\rho_m g} \quad (3)$$

where,

ℓ is a characteristic dimension for 'compact' objects
t is the thickness of sheet objects
d is the effective diameter of rod-type objects
ρ_a is the density of air
C_F is an aerodynamic force coefficient
ρ_m is the density of the missile material
U_f is the wind speed at which flight occurs
I is a fixing strength integrity parameter, i.e. the value of force required to dislodge the objects expressed as a multiple of their weight (for objects resting on the ground $I \cong 1$)
g is the gravitational constant

Equations (1), (2) and (3) illustrate the important point that the larger the value of the characteristic dimension, ℓ, t or d, the higher the wind speed at which flight occurs. These equations also show that the higher the value of the density, ρ_m, the higher is the wind speed for lift off. Thus as the wind speed in a cyclone builds up, the smaller lighter, objects e.g. gravel, small loose objects in gardens and backyards, 'fly' first. At higher wind speeds appurtenances on buildings are dislodged as the wind forces exceed their fixing resistance, and they also commence flight. At even higher wind speeds, substantial pieces of building structure, such as roof sheeting and purlins, may be removed, and become airborne.

As examples of the application of Equation (1), Wills et al considered wooden compact objects (ρ_m = 500 Kg/m^3) and stone objects (ρ_m = 2700 Kg/m^3). Assuming C_F = 1, and I = 1, Equation (2) gives ℓ equal to 110 mm for the wooden missile, but only 20mm for the stone missile, for a lift-off speed of 30 m/s.

For sheet objects, Equation (2) shows that the wind speed for flight depends on the thickness of the sheet, but not on the length and width. Wills et al [1] expressed Equation (2) in a slightly different form :

$$\rho_m t = \frac{\frac{1}{2}\rho_a U_f^2 C_F}{Ig} \qquad (2a)$$

The left-hand-side of Equation (2a) is the mass/unit area of the sheet. This indicates the wind speed for flight for a loose object depends essentially on its mass per unit area. Thus a galvanized iron sheet of 1 mm thickness with mass per unit area of 7.5 Kg/m^2 will fly at about 20 m/s (C_F =0.3).

For 'rod' like objects, which include timber members of rectangular cross-section, a similar formula to Equation (3a) can be derived from Equation (4), with the 't' replaced by d, the equivalent rod diameter. Using this Wills et al calculated that a timber rod of 10 mm diameter will fly at about 11 m/s, and a 100mm by 50 mm timber member, with an equivalent diameter of 80mm, will fly at about 32 m/s.

Flight times and distances

A missile, once airborne, will continue to accelerate until its flight speed approaches the wind speed, or until its flight is terminated by impact with the ground or with an object such as a building.

The aerodynamic force on a flying object in a wind of speed, U, can be expressed as :

Accelerating force =

$$\frac{1}{2}\rho_a (U - v_m)^2 C_D A$$

where v_m is the velocity of the missile with respect to the ground
A is the reference area for the drag coefficient, C_D

Applying Newton's law, the instantaneous acceleration of a compact object (characteristic dimension, ℓ), is given by :

To ensure the glazing is not fractured due to screen deflection under impact, the screen should be located at a distance greater than the maximum screen displacement under impact load. A minimum distance between the screen and the glazing of 1.25 times the maximum displacement of the screen under the impact load is proposed.

The screen should envelop the glazed panel. It is proposed that this be adequately achieved by either:

(a) Returning to the wall to completely envelope the opening; or

(b) Overlapping the opening by a distance measured in a plane parallel to the wall, by at least two times the distance the edge of the screen is from the wall, where the maximum distance from the edge of the screen to the wall is 300mm.; or

(c) A combination of (a) and (b).

The adoption of the overlap of two times the distance from the wall is arbitrary. It is suggested that deviation of debris within the flow stream, the available angles of attack and the potential impact of large debris articles on the side of the screen afford a low probability of debris entering around the edge of the screen. Investigation of the flight path of debris at angles less than 26.5 degrees from the plane of the wall should be undertaken to determine the extent of deflection. It is noted that while the criteria limits the opening between the wall and face of the screen to 300mm, the standard configuration of the Stormgard screen results in a gap of only about 100mm.

Proposed Test Procedure

The following test procedure is proposed for the testing of debris screens and cladding for resistance to debris and wind loads.

The test loads are:

(a) Debris Test Load:

Test Load A: End-on impact of a piece of timber 4 kilograms in mass, with cross-section dimensions of 100mm by 50mm, impacting at 20m/s.

Test Load B: Series of five steel balls of 2-gram mass (8mm diameter) impacting at 30m/s, successively.

(b) Wind Test Load:

Fatigue loading as defined in AS 1170.2-1989 clause 3.6.

In the case of debris screens to be located on walls, the magnitude of the load may be reduced due to the porosity of the screen by the factor K_p determined in accordance with AS 1170.2-1989 clause 3.4.13.

A test specimen is to be subjected to all of the test loads, with the following sequence proposed:

(1^{st}) Debris test load A

(2^{nd}) Debris test load B

(3^{rd}) Wind test load

As both debris test loads are based upon the same wind speed, and a flight distance of about 1km, either may strike the wall first. The test sequence of the larger impact followed by the smaller impacts is considered to be the more severe test.

The application of the wind load following the debris impact is consistent with the screen/cladding being on the windward wall and subject to the debris load and then following a change in wind direction being a leeward wall and subject to wind suction. This sequence is assumed to be the more severe sequence.

It is proposed that test load A should impact at the most critical location(s). The testing authority should determine the most critical location(s) (e.g. Debris Screens: centre of screen; centre of frame; fixing location – Cladding: centre of span; fixing location) by test. Test load B should then successively impact at various random locations on the screen/cladding.

The tests should be undertaken with debris impact at 90 degrees to the surface and at 30 degrees to the surface, measured in a horizontal plane.

The criteria proposed to be met for a test specimen to achieve acceptance is:
(a) to prevent a debris missile from penetrating through the screen/cladding;
(b) if perforated, have a maximum perforation width of less than 8mm measured in the plane of the wall;
(c) in the case of a debris screen, not to deflect more than 0.8 times the clear distance between the screen and the glazing, at any stage of the test.
(d) to be capable of resisting the specified wind load.

Current Building Regulations.
The current Australian Standards do not require buildings to be resistant to flying debris, if the full internal pressure is adopted in the structural design.

It is necessary that the external building fabric of essential emergency facilities, which are to be occupied/operational during a severe tropical cyclone, remains intact during the event to protect the occupants and/or the emergency facilities.

As flying debris is a load associated with wind events it is suggested that the Australian Standard for Wind Loads should include a requirement that the external fabric of shelters and essential emergency facilities be capable of resisting debris loads.

Conclusions
Rational debris resistance criteria have been presented for shelters and post disaster function buildings in the cyclonic area (AS1170.2 Region C). The external fabric of shelter buildings and essential emergency service facilities should be resistant to both debris and wind loads. This paper recommends that debris loads be considered in future revisions to the Australian Wind Loads Code.

References
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