FLYING DEBRIS TEST CRITERIA FOR POST DISASTER FUNCTION BUILDINGS IN CYCLONIC AREAS.

P.J. Mullins (Mullins Consulting)
and J.D. Holmes (Monash University and JDH Consulting)

Introduction

Flying debris associated with severe tropical cyclones is a load in addition to the wind load, which is applied to buildings. It is proposed that the external fabric of public shelter buildings and essential facilities be resistant to both debris and wind loads.

Debris may impact windward walls including doors and windows or the windward slope of steeply pitched roofs. With a change of wind direction these impacted elements of the building fabric would then be subject to suction. Clearly normal glazed windows are vulnerable to flying debris. Other elements of the external building fabric such as fibre cement sheeting, doors with inadequate latches and some thin metal sheeting may also be destroyed by debris resulting in little protection being afforded to the occupants of the building.

This paper discusses the rationale for flying debris criteria suitable for shelters and post disaster function buildings, a proposed test procedure and specification for the geometry of debris resistant screens.

The Queensland Government Department of Public Works Shelter Building Program has adopted these criteria, test procedures and specifications. The program is intended to identify and upgrade existing buildings in the cyclone region, for use as public shelters during the event of a severe tropical cyclone. BHP Building Products has constructed a test facility similar to that described by McDonald (1) and have developed *Stormgard cyclonic debris screens* to meet the shelter building requirements. G J James has developed a glazed entrance door system, which is currently being tested for compliance.

Previous Test Criteria

The first testing criterion in Australia was included in the Darwin Area Building Manual (2) following cyclone Tracy in 1974. This test specified windows and doors should withstand impact, at any angle, of a piece of 100mm by 50mm timber weighing 4 kilograms travelling at 20m/s. A more severe test was specified for cyclone refuge shelters 'end-on' impact of a piece of 100mm by 50mm timber weighing 8 kilograms travelling at 30m/s. In our companion paper this criteria was shown to be unrealistic.

Following a meeting of experts, held at the Experimental Building Station Sydney in 1977, Technical Record 440 (3) was issued. This reduced the test requirement, for windows and doors, to a piece of 100mm by 50mm timber weighing 4 kilograms travelling at 15m/s. This test has since been adopted by the Darwin Area Building Code and is also mentioned in the Australian Standard on Wind Loads AS1170.2-1989 (4) in relation to the prevention of dominant openings and resulting high internal pressures in cyclonic regions.

Wind borne debris impact test standards in the United States are discussed in a paper by Minor (5). Following investigations of glass breakages, (mainly in high-rise buildings), during several U.S. hurricanes, Pantelides et al (6) proposed a test protocol involving impacts from small spherical missiles of 2 grams. This was taken up in South Florida following Hurricane Andrew in 1992. The

Dade County and Broward County editions of the South Florida Building Code require windows, doors and wall coverings to withstand impacts from large and small debris. The large missile test, which is similar to the current Australian one, is only applicable to buildings below 9.8 metres in height. The small missile test is only applicable to windows, doors and wall coverings above 9.8 metres and differs between the two counties. The Dade County protocol uses ten 2 gram pieces of roof gravel impacting simultaneously at 26m/s, while the Broward County version uses ten 2 gram steel balls impacting successively at 43m/s.

Proposed Test Criteria

The proposed test criteria has been defined by selecting missiles which are representative of actual objects, and determining the impact speed based upon realistic flight times and distances. The following criteria were selected for shelters and emergency facilities in the cyclonic region C.

(1) All wall and roof claddings should be shown to be resistant (with protective screens installed if appropriate) to a series of five spherical steel balls of 2 gram mass (8mm diameter) impacting at 30m/s.
(2) All wall claddings should be shown to be resistant to the 'end-on' impact of a piece of timber 4 kilograms in mass with cross-section dimensions of 100mm by 50mm impacting at 20m/s.

Considering the flight threshold speed to be the mean wind speed at the peak of the design ultimate cyclone and using the method discussed in our companion paper, the following flight times and distances can be determined.

Table 1: Debris flight times and distances.

Object/speed	Height above ground (m)	Mean wind speed Terrain Cat 3 (m/s)	Time taken (s)	Distance travelled (m)
Steel Ball 30 m/s	5	30.8	127	3540
	10	36.2	14	320
Timber 20 m/s	5	30.8	80	1070
	10	36.2	45	570

The ultimate design gust wind speed upon which the mean wind speeds are based is determined from AS1170.2 for post disaster function buildings as 77m/s. This wind speed approaches the upper wind speed for a Category 4 cyclone of 280 km/hr.

From the table it can be seen that the flight time and distance vary dependent upon the wind speed. It can also be seen that for typical building heights the flight times and distances are realistic.

Proposed Debris Screen Geometry

The screen material may vary depending upon the building owner's requirements. A louvre type mesh could be used to afford sun protection, or a finer mesh where vision is to be maintained. The screens may be fitted to provide security. Window cleaning also needs to be considered in the design of the screen. Following is a discussion of the geometry requirements for debris screens to afford reasonable level of protection of an opening.

To be consistent with the debris criteria the largest aperture in the screen should be 8mm or less.

$$\text{Acceleration} = \frac{\frac{1}{2}\rho_a (U - v_m)^2 C_D A}{\rho_m \ell^3} = \frac{\frac{1}{2}\rho_a (U - v_m)^2 C_D}{\rho_m \ell} \quad (3)$$

taking A equal to ℓ^2.

The same equation applies to 'rod' type objects when ℓ is taken as the length (A is the cross-section area).

Equation (3) shows that heavier and larger objects have lower accelerations, and hence their flight speeds are likely to be lower than smaller or lighter objects. The Equation also shows that the initial acceleration from rest (v_m=0) is high, but the acceleration rapidly reduces as the difference between the missile speed and the wind speed reduces, so that the wind speed is approached very slowly. Of course the missile speed cannot exceed the wind speed.

Equation (3) can be integrated to obtain the time taken to accelerate to a given speed, v_m, and the distance travelled in this time. These equations are as follows :

Time taken to accelerate from 0 to v_m,,

$$T = \frac{v_m}{kU(U - v_m)} \quad (4)$$

Distance travelled,

$$s = U\left[T - \left(\frac{1}{kU}\right)\ln(1 + kUT)\right] \quad (5)$$

where $k = (\rho_a C_F)/(2\rho_m \ell)$ with units of (1/m).

Using Equation (5), the flight times and distance travelled by a) a steel ball of 8 mm diameter and 2 gram mass, and b) a 4 Kg piece of timber of 100mm by 50 mm cross section, and length 1.6 metres, have been calculated, for a wind speed, U, of 32 m/s (a reasonable value for a design cyclone in an urban area in Region C), and are given in Table I.

Table I

Object / speed	Time taken (secs)	Distance travelled (metres)
Steel ball to 20 m/s	5.4	71
Steel ball to 30 m/s	49	1270
Timber piece to 20 m/s	69	910
Timber piece to 30 m/s	625	16300

The Table shows the much longer flight times and distances for the larger object. To reach 30 m/s, the 4 Kg timber missile would need to travel for 10 minutes, and over 16 kilometres. Shortly after Cyclone 'Tracy' a larger (8 Kg) timber missile travelling at 30 m/s was originally specified for cyclone refuge shelters in Darwin. Fortunately such an unrealistic specification was dropped a year or two later.

Trajectories

Tachikawa [2] carried out a fundamental study of the trajectories of missiles of the flat plate, or sheet, type. Aerodynamic forces on auto-rotating plates were measured in a wind tunnel. These results were then used to calculate the trajectories of the plates released into a wind stream. Free-flight tests of model plates with various aspect ratios were made in a small wind-tunnel, and compared with the calculated trajectories. A distinct change in the mode of motion and the trajectory, with initial angle of attack of the plate, was observed. The calculated trajectories predicted reasonably the upper and lower limits of the observed trajectories. A later study by Tachikawa [3] extended the experiments to small prismatic models as well as flat plates, and gave a method of estimating the position of a missile impact on a downstream building. The critical non-dimensional parameter for determination of trajectories used by Tachikawa was $K = \rho_a U^2 A/2mg$, where :

ρ_a is the density of air
U is the wind speed
A is the plan area of a plate
m is the mass of the missile
g is the gravitational constant

This parameter can also be expressed as the product of three other non-dimensional parameters :

$$K = \frac{1}{2}\frac{\rho_a}{\rho_m}\frac{U^2}{g\ell}\frac{\ell}{t} \qquad (6)$$

where ρ_m is the missile density
t is the plate thickness
ℓ is $\sqrt{A}$, i.e. a characteristic plan dimension
$(U^2/g\ell)$ is a Froude Number.

Conclusions

A review of the mechanics of flying debris in extreme winds has been given. Although relatively little research on this topic has been done, compared with that on direct wind loading of buildings, models of the phenomenon, based on dimensional analysis, are sufficiently developed to allow reasonably rational criteria to be developed. Further verification of these models in wind tunnels, or by full-scale observation, is desirable.

References

1. Wills, J., Wyatt, T. and Lee, B.E. Warnings of high winds in densely populated areas. United Kingdom National Coordination Committee for the International Decade for Natural Disaster Reduction, 1998.

2. Tachikawa, M. Trajectories of flat plates in uniform flow with application to wind-generated missiles. *Journal of Wind Engineering and Industrial Aerodynamics*, Vol. 14, pp443-453, 1983.

3. Tachikawa, M. A method for estimating the distribution range of trajectories of windborne missiles. *Journal of Wind Engineering and Industrial Aerodynamics*, Vol. 29, pp175-184, 1990.