Testing and Review of Porous Impact Protective Systems for Windstorm Debris and Associated Standards

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Various standards for impact protection of window fenestration during extreme wind storm events were analyzed and compared. A 120.5mm gas cannon test apparatus capable of fulfilling multiple standards with little or no modification was designed. The test apparatus was manufactured and is capable of applying the large missile test to impact protective systems. The test apparatus exceeds the specifications of AS1170.2 ‘Structural Design Actions – Wind Actions’. The large missile test was conducted on Crimsafe® Cyclone Screening in accordance with AS1170.2 using Australia’s highest wind region velocity (44ms⁻¹). Additional variables not specified by AS1170.2 were monitored and the test results used to discuss the safety, suitability and relevance of AS1170.2 to porous impact protective systems. It was found that AS1170.2 contains inadequate detail to safely qualify porous impact protective systems for use in realistic conditions. Conclusions from the test and discussion were used to produce recommendations regarding modification of AS1170.2 or the creation of a standard specific to porous impact protective systems.

Nomenclature

Impact protective system
Construction applied, attached, or locked over an exterior glazed opening system to protect that system from windborne debris during high wind events.

Maximum residual deflection
Plastic deformation of an element or component after an applied force has been removed.

Maximum dynamic deflection
Greatest deformation of an element or component during the missile impact.

Porous impact protective system
An assembly whose aggregate open area exceeds ten percent of its projected surface area.

Fenestration assembly
The construction intended to be installed to fill a wall or roof opening.

I. Introduction

Tropical cyclones are intense cyclonic windstorms that occur in tropical areas such as the north-east coast of Australia. Cyclones also occur in the South China Sea where they are known as typhoons and in the Caribbean where they are known as hurricanes. Research into the mitigation of the structural effects of windstorms has worldwide application. Windstorm research contributes to a decrease in the economic consequences of a catastrophic event and casualty reduction within the population [1].

Wind loading is a significant environmental load for structures as windstorms cause significant damage to property, especially in tropical cyclone regions where windstorm effects are devastating. Wind loading is generally considered as three separate cases; a bluff body resultant force exterior to the structure, a pressure differential between the interior and windfront exterior of the structure and windborne debris impacting the building at a percentage of the windspeed [2].

Structures with openings to the windfront may experience internal pressures equal to or greater than external pressures in a severe windstorm. This is caused by inertial effects and is amplified if the windfront area opening is

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small relative to the internal volume of the building. The critical design case should be considered whereby high positive peak internal pressures are generated by gust cycles and considered in conjunction with negative external pressures. If a structure has an opening toward the windfront, such as the accidental failure of window fenestration due to windborne debris, the probability of catastrophic failure is increased considerably [3]. As stated in ASCE 7; the internal pressure coefficient can increase by a factor of four. This increases the net outward acting pressure on a structure by a factor of two [4].

II. Background

A. Methods to protect window fenestration

The fluctuating pressure differential between the interior and exterior of a structure can be reduced by preventing penetration of the building envelope by airborne debris. This also assists in mitigating wind and rain damage to the interior of the structure [5]. There are a number of methods that integrate into a window fenestration to prevent penetration by airborne debris; shutters and wire mesh being the most popular. Shutters must sustain a pressure differential, are not transparent and must be mechanically operated. Porous mesh screens are transparent and can be permanently fitted without obstructing the function of the fenestration. This report will focus solely on porous screens to the exclusion of shutters as research into the establish shutter industry would contribute less to public safety than research into the less tested and established screen industry.

B. Standards associated with porous impact protective systems

This report will focus on thorough analysis of three standards:

a. Australian Standard 1170.2 ‘Structural Design Actions – Wind Actions’ (Standards Australia, 2011) [6];

b. Florida Building Code 2012 Section 1626 ‘High Velocity hurricane Zones – Impact Tests for Wind borne Debris’ (Florida Department of Business & Professional Regulation, 2010) [7];

c. TAS 201 ‘Florida Impact Test Procedures’ (Florida Department of Business & Professional Regulation, 2010) [8]; and


Standards will be referred to as the Australian Standard (AS1170.2), Florida Building Code (FBC) and the ‘International’ Standard (ASTM 1886).

All standards require window fenestration to undergo not only missile impact testing but also cyclic pressure differential testing. A window ‘fenestration’ is the entire window assembly (including glazing and frame) as it would be installed a structure. Since the structural use of cyclone debris screening cannot be predicted and is porous in nature; cyclic pressure differential testing of singularly the screen have questionable relevance to its intended application or structural integrity. Consequently, this report will not concern cyclic pressure differential testing.

C. Comparison of Standards

A summary standards comparison table it attached at appendix 1.

The ASTM and FBC both make provisions for multiple plane impact protective systems; these shall be ignored due to the scope of this discussion. The ASTM states that the plane shall not be penetrated or fasteners disengaged and the FBC states that no crack longer than 127mm long or wider than 1.6mm shall be tolerated. The AS does not adequately state any failure criteria.

Mounting specifications are only stipulated in the FBC which is strangely specific in stating that the impact protective device must be mounted to a specific species of pressure treated timber. ASTM E1886 ambiguously states that the screen should be mounted as per the fenestration and AS1170.2 makes no demand on the mounting of mesh screens.

Both ASTM E1886 and the FBC state specific, extensive criteria that must be fulfilled, documented and submitted in order for the design to be approved as cyclone resistance to its intended application. AS1170.2 lacks any and all detail in this regard whereby the documented evidence required is at the discretion of the approving authority.
Missiles attain a maximum velocity as a percentage of the windspeed in the windstorm. The FBC and ASTM 1886 stipulate one windspeed. These are 15.2 m/s and 24.4 m/s respectively. Maximum wind speeds, dictated by AS1170.2, are both higher and region specific as detailed in Figure 1 below. This is significant as it is established from (G. Fernandez, 2010) that the failure of cladding is directly proportional to the kinetic energy of the projectile which is directly proportional to the missile velocity.

Calculations for the missile kinetic energy are shown below. It should be noted that the FBC requires two large missile impacts (see Annex B); however, this is still hugely disparate from the energy absorption requirements of AS1170.2.

\[
E_k^{\text{ASTM}} = \frac{2 \times (24.4)^2}{41} = 1.22 \text{ Kj}
\]

\[
E_k^{\text{FBC}} = \frac{2 \times (15.2)^2}{41} = 474 \text{ j}
\]

\[
E_k^{\text{AS1170.2}} = \frac{2 \times (44.0)^2}{40} = 3.87 \text{ Kj}
\]

Consequently; \(E_k^{\text{FBC}} < E_k^{\text{ASTM}} < E_k^{\text{AS1170.2}}\)

Both the ASTM and FBC state that at least three test specimens and one possible redundancy are to be used for a singular outcome. The ASTM states that the large and small missile tests can be combined as long as the small missile test is conducted first. The AS does not specify a number of test specimens; leaving it implicit that one specimen will fulfill the requirement. One test specimen is not sufficient to establish consistency in the experimental outcome.

Both the ASTM and FBC state that each specimen shall be subject to 3 small missile impacts. The AS states that each specimen shall be subject to only 1. As the small missile test is designed to simulate airborne debris that occur more frequently than large debris in a windstorm; it is appropriate to require that an impact protective system sustain multiple small impacts. This would also increase the rigor of the small missile test.

Both the ASTM and FBS require 10 individual 8mm, 2g steel bearings per ‘small missile impact’ whereas the AS only requires 1 8mm bearing per impact. Due to the significantly larger amount of kinetic energy involved with multiple missiles it is reasonable to state that both the ASTM and FBC are small missile tests are significantly more strenuous than the AS.
The ASTM and FBC are similar in specifying Species, Weight (4.1kg), length, treatment and tolerance of timber to be used for the missile whereas the AS only states the weight and cross sectional area of the timber. Unless the large missile undergoes critical failure or fracture in the test (this is unlikely) the specific mechanical properties of the timber are largely irrelevant (except weight, cross sectional area and to a lesser extent; length). Specifying the mechanical properties of the timber could be avoided by adding a clause stating ‘The large missile will not undergo any significant deformation during impact with the test specimen’ and ‘descriptions of the missile and screen (photographs?) shall be included in the test report’. As such the large missile requirements of the Australian standard are adequate, however, the mass tolerance of the missile should be stated clearly and be a positive value to discourage weight shaving during testing. Further, as long as the missile head is timber; the trailing portion of the missile could be composite as long as the mass is kept in accordance with the standard.

Both the ASTM and FBC state that each test specimen shall be subject to two large missile impacts per test specimen whereas the Australian standard only states that one impact is required. Even though the ASTM and FBC require multiple impacts; the large missile velocity require by the AS still requires that the AS test specimen dissipate the largest energy. Further; since the two impacts required by the ASTM and FBC are disparate and in separate locations; the kinetic energy transferred by the AS is localized to a single location. As such the AS single large missile impact requirement is a more rigorous standard than the ASTM and FBC.

Both the ASTM and FBC state that the test specimen must sustain large missile impacts at three of the rectangular specimen’s most common failure nodes; the long edge, short edge and corners. The AS does not state an impact location for the large missile test; leaving it implicit that the impact can occur at the centre (strongest) of the porous impact protective device.

The ASTM requires the velocity measuring device to be calibrated using a 500fps high speed video camera or independently calibrated speed measurement system. The FBC requires a timing system calibrated and certified by an independent qualified agency approved by the Building Code Compliance Officer. The AS makes no statement for calibration requirements.

The ASTM states that the missile free flight distance is equal to 1.5 times the length of the missile and that this distance shall be no less than 1.80 m. The FBC states that the free flight distance shall be 9 feet plus the length of the missile. The AS makes no statement for the missile free flight distance. As the missile is not being acted upon by the acceleration forces of the missile propulsion device the free flight distance is of little relevance to the outcome of the test; the air resistance will also dissipate a small amount of the missile kinetic energy. As such a free flight distance is not necessary to specify in terms of the length of the missile propulsion device barrel or missile length but should only be relevant to the distance between the two through-beam photoelectric sensors used to measure its velocity as well as the offset of the second photoelectric sensor from the test specimen.

D. Design and construction of test apparatus

The most repeatable manner to launch a 4kg projectile at 44 ms-1 is by using a compressed air cannon with a fast opening valve [9]. UNSW@ADFA’s medium velocity gas gun (MVGG) met this criteria but only had a 38mm barrel. As AS1170.2 stipulates 100x50mm timber to be used the minimum which necessitates a barrel of at least 112mm. Additional clearance must be left to prevent hardwood from slowly eroding the barrel. A 127x3.25mm cold drawn steel tube was selected as the barrel with safety factor of 14 for longitudinal stress.

The barrel was adapted to the magnetic valve through the diffuser. The diffuser is bonded to the barrel using structural methacrylate adhesive with a shear strength of 29.7 Nmm⁻². Structural resins can achieve strengths of up to 70% of a welded joint and the diffuser joint has a safety factor of 20 through conservative momentum calculations.

Increasing the diameter from 38mm to 120.5mm increased the recoil force of the gun by a factor of 10 to a peak value of 9.12 kN. The existing rubber damping system would shear at this value and a new system had to be designed using four M101006070 Mackay Multicushions (100mm diameter). It was deemed desirable that the existing 38mm barrel work interchangeably with the new 120.5mm barrel and recoil damper so the new damping system had to be accommodated in the area previously occupied by a system of lesser capacity and volume.
The increase in diameter was accomplished by mounting the recoil system using a saddle and two carrier rails as depicted in figure 2 above. The new recoil compensation system does not alter the height of the magnetic valve itself. This enables the quick exchange of barrels without modification of the valve mounting assembly or carrier supports. Second order linear finite element analysis was carried out on the saddle using Catia as depicted in figure 3 below. The peak saddle stress was 39 Mpa with a deflection of 0.2mm.

The large missile is constructed of Spotted Gum and is both composite and modular in nature. Spotted gum is a native Australian hardwood and selected due to its high density (934 KgM⁻³). The higher the density of the missile, the shorter the missile, the shorter the free flight distance during testing and the smaller the impact chamber has to be. The large missile utilized a 120.3mm Delrin® sabot to achieve a seal with the barrel. The sabot is non discarding and affixed to the rear of the missile using four timber screws. A Teflon® slider is fastened near the tip of the missile to prevent friction with the barrel and ensure missile alignment within the barrel. The missile tip is removable and fastened to the missile by two countersunk 140mm timber screws. The missile tip is removable so the missile tip can be replaced and the missile reused when the tip sustains damage. A reflector is bonded to the missile tip to activate the velocity photo sensors. It is important to bond the reflector close to the missile tip so that the tip cannot activate the photo sensor and give a misleading velocity value.
It was deemed appropriate that the target mount be designed to be rigid and modular in nature. A rigid target mount would prevent the mount from deflecting and absorbing energy during impact. A non rigid target mount would give misleading results and be difficult to qualify and incorporate into a standard. This was accomplished by using 75x75x8mm steel angle and extendable bracing legs against the rear wall. The target mound should be able to mount a variety of screen sizes yet retain its rigidity. This was accomplished by making the design modular; the horizontal rails can be lowered and raised and the vertical interchanged to test up to 1100x1800mm screens in a variety of locations. The target size is limited by the impact chamber size and the position of the barrel.

Figure 5 - The modular, rigid target mounting solution

III. Testing Crimsafe® Cyclone Screen under AS1170.2

The large missile test was conducted on an 800x800mm Crimsafe® Cyclone Screen with a 100mm standoff frame in accordance with AS1170.2 using the test apparatus described earlier. The notable variables are tabled below

<table>
<thead>
<tr>
<th>Test</th>
<th>Missile Weight</th>
<th>Impact Velocity</th>
<th>Kinetic Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4.015 Kg</td>
<td>44.85 ms⁻²</td>
<td>4038 J</td>
</tr>
<tr>
<td>Minimum required</td>
<td>4.000 Kg</td>
<td>43.56</td>
<td>3870 J</td>
</tr>
</tbody>
</table>

The missile impacted the centre of the screen and caused the following deformation.

Figure 6 - Front view showing residual frame deformation

Figure 7 - Image showing frame failure in tension (top) and buckling (bottom)
Test Outcomes:
a. There was no striping or separation of the mesh from the frame or piercing of the mesh itself.

b. The main mode of energy absorption through deformation occurred in plastic deformation of the mesh and through bending of the standoff frame as seen in figures.

c. The inner portion of the standoff frame failed in tension and the outer portion buckled in compression as seen in figure.

d. The screen sustained 138mm of residual deformation.

e. Analysis of the high speed footage of the test indicated 146mm dynamic deformation.
IV. Discussion

A. Testing of Crimsafe Cyclone Screen using large missile

The large missile test conducted at the UNSW@ADFA impact laboratory met or exceeded the large missile test requirements as stipulated by AS1170.2. Where detail was lacking under AS1170.2 best practice was employed to prevent ambiguity and ensure academic integrity. For example; mounting requirements were not stipulated thus a rigid frame was used and possible deflection discounted using high speed photography.

Failure criteria are not explicitly stated in AS1170.2 but the screen suffered no damage that would disqualify it under either standards ASTM E1886 or the FBC. It would however fail the mounting requirements of both standards. ASTM 1886 states that the screen must be offset from the fenestration from which it is installed to protect +25% and the FBC states that the screen must not make contact with the same fenestration. The screen offset frame is 100mm in depth and the screen dynamically deformed by 146mm meaning that the missile, although deflected, would have penetrated 46mm into the building envelope. This would break any glasswork behind the screen and enable a fluctuating pressure differential to be established between the building and the external environment as the screen is porous in nature. As stated in the introduction this could increase the internal pressure coefficient by a factor of four and lead to structural failure of the building.

Although the Crimsafe® Cyclone Screen meets or exceeds all requirements of the AS 1170.2 large missile test it would require modification to qualify for either foreign standards analyzed in this report. If installed as intended the screen could fail and contribute to the catastrophic failure of the building it is intended to protect.

B. Relevance of AS1170.2 ‘Structural Design Actions – Wind Actions’

The ASTM, FBC and AS are all designed to test the ‘fenestration’ or entire ‘assembly’. This includes the impact protective system as well as the frame and component for which the system is protecting (eg; window). Consequently each standard makes provisions for the fatigue associated with cyclic pressure loading. Porous impact protective systems are not affected by cyclic pressure loading due to their large open area compared to the projected area. Any cyclic pressure testing on the IPS would be on no consequence. Since IPS manufacturers control only the IPS and not the entire fenestration (this is the responsibility of the design engineer of the structure) it is appropriate to state that the IPS complies with the requisite building code without conducting cyclic pressure fatigue testing. It is the responsibility of the design engineer to ensure that the entire fenestration adheres to the requisite building code (including cyclic pressure fatigue testing) given the robustness of the IPS and the maximum dynamic deflection for the appropriate wind zone.

The main contributing parameters of the large missile are its weight, velocity, cross section and to a lesser extent length. It is possible to have a composite missile that weighs 4Kg and performs similarly to a wholly wooden missile of the same mass. The composite missile could be shorter and easier to test. Further; the composite missile could have interchangeable tips and thus be re-useable. It would be appropriate to use a composite missile in place of a wholly wooden missile if it was documented that no significant deformation or fracture occurred during testing.

Australian Standard 1170.0 gives only 1 clause relevant to the impact of debris during a windstorm whereas ASTM and FBC have entire standards to define the performance of IPSs during a hurricane/windstorm. It would be appropriate to create a standard and test procedure relevant to this application is a similar fashion to ASTM 1996 – 1886 and FBC 1626 – TAS 201.

The speed of missiles fired during both the small and large missile tests is dictated by region. These windspeeds are sourced from empirical meteorological evidence and are appropriate for the intended structure location. The missile velocity is simply given as 0.4xWindspeed. This figure seems arbitrary and is highly disproportionate when compared to the much lower velocities given in ASTM E1886 and the FBC (24 and 15 ms\(^{-1}\) respectively). More consideration needs to be applied to the velocity of large projectiles in a severe windstorm. If test velocities can be safely lowered whilst still reflecting realistic debris then cyclone screens could become more affordable, aesthetic and accessible.

AS1170.2 makes no statement for the mounting requirements of the screen for testing. ASTM E1886 states that the test should be conducted as per installation intention; however, manufacturers of porous impact protective
systems cannot predict the mechanical properties of the intended customer’s fenestration. The FBC is prohibitively specific and nebulous in its mounting requirements. It would be appropriate to require that the mounting frame be manufactured as to be considered ideally rigid when compared to the test specimen, that the specimen shall be fixed to the frame using the fasteners specified by the manufacturers and that failure of these fasteners during testing should be considered a failure criteria.

V. Conclusion and Recommendations

Damage and loss of life due to extreme windstorm events such as cyclones causes significant emotional and financial hardship to populations living in tropical regions. The structural integrity of building is compromised when a fluctuating pressure differential is established inside a building that is caused by a small windfront opening relative to the building internal volume. The structural integrity of buildings can be preserved by preventing penetration of the sealed building envelope by windstorm debris. Porous impact protective systems are an effective means to deny penetration of the building envelope whilst being transparent, relatively aesthetic and affordable. A number of both local and international standards are applied to porous impact protective systems. ASTM E1886 and the FBC contain some nebulous detail, are prohibitive and less rigorous than AS1170.2. AS1170.2 lacks critical details and provisions for standoff and dynamic deflection. AS1170.2 is possibly too rigorous and a revision of large debris in a wind storm could improve accessibility of porous impact protective systems and consequently public safety.

Although testing of the Crimsafe® cyclone screen yielded no component failure the missile was still able to penetrate the building envelope. The lack of detail and provision present in AS1170.2 enables Crimsafe® Cyclonic Screening to meet the requirements of the large missile test whilst being unsafe to install according to ASTM E1886 and the FBC. If the screen was installed and impacted as per the standard during a windstorm the fenestration would fail to sustain a pressure differential and could contribute to catastrophic failure of the building.

The Australian Standards Association should review AS1170.2 and consider incorporating the recommendations below. Public safety regarding porous impact protective systems would significantly benefit from a standard specific to their application; free from subjection to cyclic pressure differentials and containing the appropriate level of detail.

**Recommended Standard**

| Number of tests | 3 for large missile, 1 for small missile |
| Types of test | Large and small missile |
| Mounting requirement | Rigid frame using fasteners as per manufacturer’s specification. |
| Large and small missile velocity | Review of AS1170.2 wind speed formula is recommended |
| Small missile specification | 8mm diameter 2g steel ball bearing |
| Small missile number of impacts | 3 |
| Small missile number of missiles per impact | 10 |
| Small missile location of impacts | +/- 100mm centre, corner, long edge |

**Large missile specification**

| Large missile number of impacts | 1 |
| Large missile location of impacts | Centre +/- 100mm |
Pass/fail criteria

a. Penetration of the mesh pane
b. Dynamic deformation greater than the standoff distance of the installation
c. Disengagement of fasteners from the frame
d. Holes of combined area greater than 25 cm²

Offset requirements

Velocity accuracy

Maximum dynamic deflection + 10%

±2 % when speed < 23 m/s, and
±1 % when speed > 23 m/s.

Missile free flight distance

Minimum missile length + sensor interval separation.

Sensors must be positioned such that velocity measurement begins after the entire missile leaves the barrel and ends before the missile impacts the screen.

Appendix

1. Comparison table of relevant standards.

Acknowledgments

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Bibliography


**Consulted**


## Standards Comparison Table

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<td><strong>Number of Tests</strong></td>
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<td>3 tests</td>
<td>Not specified</td>
</tr>
<tr>
<td><strong>Types of Tests</strong></td>
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<td>Large and small missile</td>
<td>Large and small missile</td>
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<td><strong>Mounting Requirement</strong></td>
<td>As per installation fenestration</td>
<td>Entire assembled unit including 50x100mm species specific pressure treated timber</td>
<td>Not specified</td>
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<tr>
<td><strong>Small Missile Number of Impacts</strong></td>
<td>3 impacts</td>
<td>3 impacts</td>
<td>1</td>
</tr>
<tr>
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<td>10 missiles</td>
<td>10 missiles</td>
<td>1</td>
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<tr>
<td><strong>Small Missile Velocity (Max)</strong></td>
<td>39.62 m/s</td>
<td>40 m/s</td>
<td>44.00 m/s</td>
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<td><strong>Small Missile Location of Impacts</strong></td>
<td>Specified 3-6 locations in 3 separate test procedures</td>
<td>0.19m² distributed impact at centre, edge and corner</td>
<td>Not specified</td>
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<tr>
<td><strong>Large Missile Specification (Max)</strong></td>
<td>Species, Weight (4.1kg), length and tolerance of ‘lumber’ that is free from defects</td>
<td>4.1kg 102x51mm solid S4S nominal #2 surfaced dry southern pine.</td>
<td>4kg 100x50mm ‘timber’</td>
</tr>
<tr>
<td><strong>Large Missile Velocity (Max)</strong></td>
<td>24.38 m/s</td>
<td>15.2 m/s</td>
<td>44.00 m/s</td>
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<tr>
<td><strong>Large Missile Number of Impacts</strong></td>
<td>1 - (wind zones 1-3)</td>
<td>2 - (wind zone 4)</td>
<td>1</td>
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<td><strong>Large Missile Location of Impacts</strong></td>
<td>Specified 3-6 locations in 3 separate test procedures</td>
<td>Center and long edge, short edge and corner.</td>
<td>Not specified</td>
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<tr>
<td><strong>Pass/Fail Criteria</strong></td>
<td>- No penetration of innermost plane</td>
<td>No crack forming longer than 5 inches 127 mm long and 1.6 mm wide</td>
<td>Not specified</td>
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<td>- No opening through which a 76mm sphere could pass</td>
<td>No fasteners to become disengaged (wind zone 4 only)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Fasteners shall not become disengaged (wind zone 4 only)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>International Standard</td>
<td>Florida Building Code</td>
<td>Australian Standard</td>
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<td>--------------------------------</td>
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<td>---------------------</td>
</tr>
<tr>
<td><strong>Offset Requirements</strong></td>
<td>- The maximum dynamic deflection as measured plus 25%</td>
<td>Nil contact with device intended to protect</td>
<td>None</td>
</tr>
<tr>
<td><strong>Calibration Requirements</strong></td>
<td>500fps high speed video camera, or Independently calibrated speed measurement system</td>
<td>Timing system shall be calibrated and certified by an independent qualified agency approved by the Building Code Compliance Officer</td>
<td>Not specified</td>
</tr>
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</table>
| **Velocity Accuracy**          | ±2 % when speed < 23 m/s  
±1 % when speed > 23 m/s | two, through-beam photoelectric sensors accurate to ± 2% of measured speed. | Not specified |
| **Conditioning Requirements**  | 4 hours at 15-35°C | Not Specified | Not specified |
| **Free Flight Distance**       | Propulsion device minimum distance from the specimen equal to 1.5 times the length of the missile. This distance shall be no less than 1.80 m, | The distance from the end of the cannon to the specimen shall be 9 (nine) feet plus the length of the missile. | Not specified |