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Influence of Impact Locations for Windborne Debris Impact Testing on Cladding Products

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Abstract

The aim of this paper is to demonstrate the importance of selecting the impact locations for windborne debris impact testing using the timber missile, because the critical impact location differs significantly between three of the common cladding products (conventional metal cladding, Structural Insulated Panels (SIPs) and garage doors) used in Australia. As buildings with an envelope that is deemed impact resistant can be designed to significantly lower design wind loads, testing is often conducted to demonstrate compliance. It is concerning that no regulatory documents currently exist to specify the testing requirements. This allows a worrying trend to continue, that sees many building products being tested using a single midspan impact trial. In all of the three building products this impact location has a rare chance of failure compared to other locations.

Introduction

An investigation into the effect of target location, momentum and kinetic energy of timber missiles (rod objects) impacting on conventional metal cladding has recently been documented by Frye et al (2012) document. However, the advance of new cladding products such as Structural Insulated Panels (SIPs), also known as "composite" or "sandwich panels" (these products comprise a foam core with two exterior metal skins), and the recent emphasis on garage doors has brought about a new suite of critical impact locations. In several cases the critical locations differ significantly not only to those established for conventional metal cladding but sometimes also within the same product range (i.e. roller doors compared to other roller doors). The main driver for these differences is in most cases the different connection mechanisms employed (i.e. between panels or garage or roller door slats).

The wind loading standard AS/NZS 1170.2:2011 has introduced the windborne debris target velocity for timber missiles as either 10% or 40% of the regional cyclonic wind speed depending on whether the missile has a vertical or horizontal trajectory. The superseded wind loading standard used an arbitrary 15 m/s timber missile velocity value for all cyclonic regions. The building industry welcomed the refinements, however, several uncertainties remain. No definitions of pass/fail criteria are stipulated nor are guidelines for impact location provided. In fact in some cases, structural engineers do not agree upon which location is critical, given the complexity due to the lack of understanding of the new building products.

AS 4055—2006 stipulates that domestic buildings shall be designed for high internal pressure in cyclonic regions. Non-residential buildings, in contrast, do not require to be designed for high internal pressure, if all building envelope components can be shown to be capable of resisting impact loading from windborne debris for the specified missile speeds (see Clause 5.3.3 of AS/NZS 1170.2:2011). However, if the envelope of a building deemed-to-be impact resistant is breeched, the risk of significant damage is increased, given that high internal pressure can add significantly to the overall wall and roof wind loads.

This lack of regulation on pass/failure criteria and lack of guidance on likely critical target locations, allows a product to be impact tested using a single debris impact trial at the cladding midspan. However, experience during impact testing by the Cyclone Testing Station (using a minimum of three different impact locations) has found that midspan impact locations are usually not critical. This demonstrates that products impact tested at midspan only are likely to have unconservative results, and raises significant concerns that this approach is likely increasing risk, as well as creating a false sense of security amongst specifiers, designers and building authorities. This paper will demonstrate the importance of selecting the critical locations for impact testing.

Conventional Metal Cladding

For this paper, the investigation into static load testing and experimental impact testing of metal cladding by Frye et al (2012) is summarized, as it shows the response of conventional metal cladding to impact loading.

Static Load Testing

Extensive testing was conducted to identify the load distribution depending on impact location. The wall cladding used for the first set of tests conducted was 0.42 mm Base Metal Thickness (BMT) corrugated cladding manufactured from G550 steel (rolled from steel coil of minimum 550 MPa yield strength).

The cladding was screw fixed according to manufacturer's instructions to Z15015 purlins (1.5 mm BMT G450 steel) using 14 - 10 × 25 mm self-drilling metal screws at alternate valleys. A single span arrangement was investigated with the distance between girts being fixed at 900 mm.

Figure 1 shows the initial set-up using two lapped sheets, and a grid of thirty points on the specimens, identified as points A0 to E5. The spacing between these grid points (x = 300 mm, y = 225 mm) being parallel and perpendicular to the girts, respectively, and the force sensor was located at point A0.

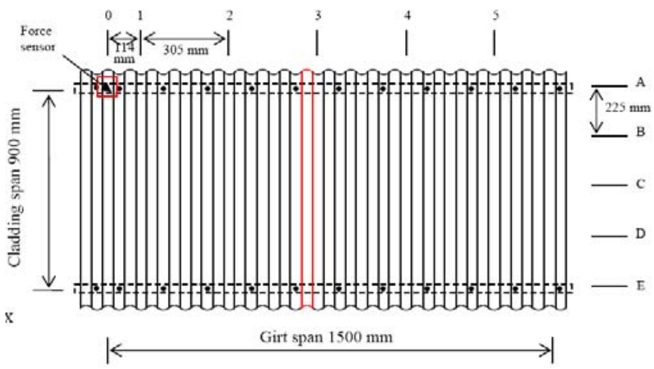

Figure 1. Diagram of experimental set-up. (Frye et al, 2012)

The static force and deflection tests were performed in the elastic region of the cladding material with the aim of investigating the fundamental behaviour of this cladding profile. A load of nominally 500 N was applied at each of the grid points via a piece of timber with a cross-sectional area of 100 × 50 mm.

The response of the system to static loads is presented in terms of the z reaction at A0 (i.e. R_z). Figure 2 show the reaction R_z non-dimensionalised with the reaction R_z when the static load is applied at A0. The plotted data represent the average of two series of tests undertaken. Since the loads were applied to the cladding in the (negative) z direction, the largest reaction forces were measured in this direction.

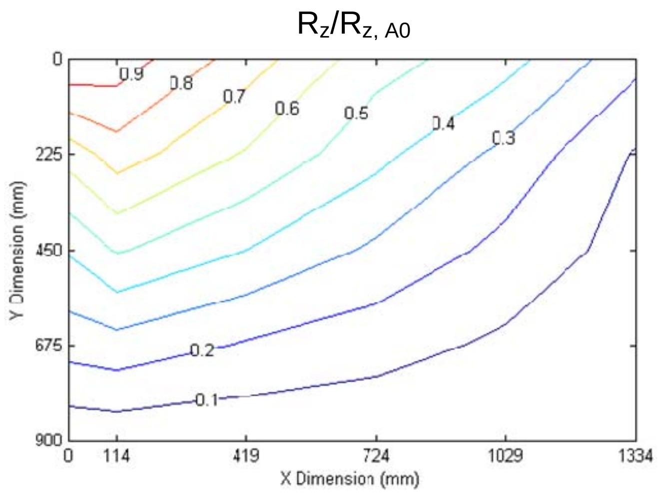

Figure 2. Influence coefficients for reactions in z direction. (Frye et al, 2012)

The plot in Figure 2 shows the influence coefficients for the reactions at A0 in the z direction, i.e. perpendicular to the cladding and parallel to the loading direction. These results are distributed as expected, with the reaction being equally shared between the two girt supports when the load was applied at midspan of the girt. Similarly, equal sharing of reaction is evident when the load was applied at midspan along the left edge of the cladding. The sharing of reactions when the load was applied at the geometric centre of the cladding specimen was expected to be in equal amounts (25%) to all four corner supports and the measured reactions agree overall.

For the static load tests, deflections were also measured at selected locations on the cladding surface. The analysis of these deflection measurements provides a description of the cladding behaviour under concentrated loading in the material's elastic region. Six dial gauges were positioned at grid points B1, B2, B3, C1, C2 and C3. A nominal load of 500 N was then applied at each grid point A1 to E5 in turn and deflections measured at the same time as the reactions at A0. The actual deflections were measured in the negative z direction; however, for simplicity they are plotted as absolute numbers in Figure 3.

From the deflection contour plots below it is evident that the largest deflection occurs when the cladding is loaded at midspan, i.e. half way between the two supporting girts. When the specimen was loaded off centre, (i.e. lines 1 and 2) the largest deflections were measured at midspan (i.e. line C).

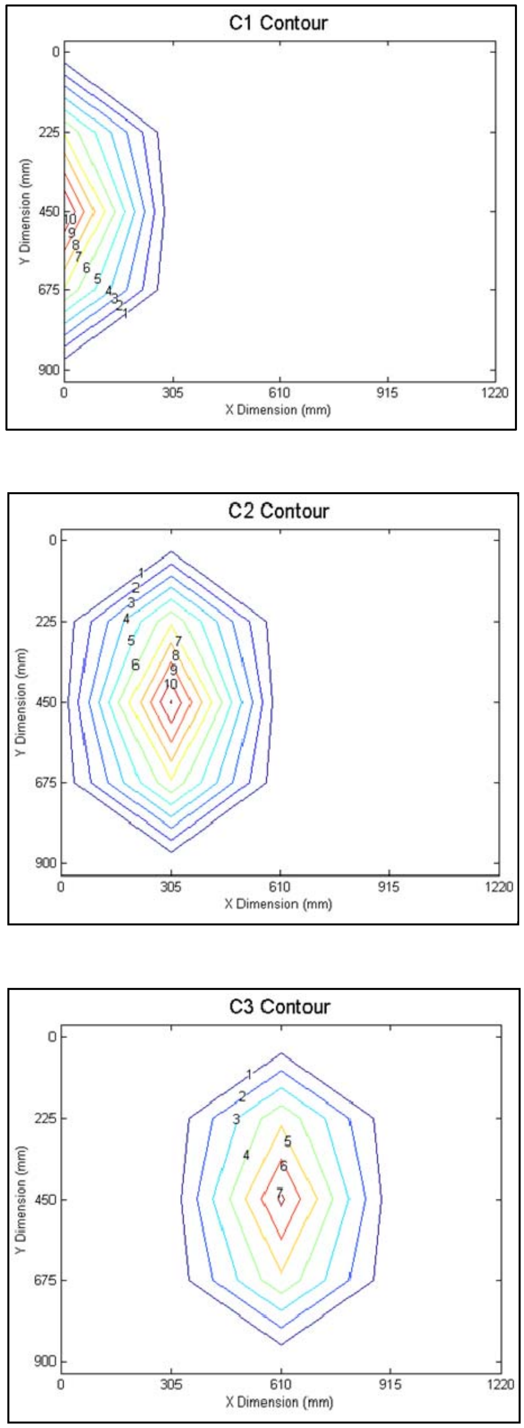

Figure 3. Cladding deflections (mm, absolute) in the z direction with loading at C1 (top), C2 (centre) and C3 (bottom). (Frye et al, 2012)

Frye et al (2012) showed that this behaviour conformed to simple beam theory and the cladding essentially acted like a beam member along its corrugations. Furthermore, the measured data indicated that very little of the applied load is transferred across the corrugations, as can be seen from the rapid decay of vertical deflections in the x direction (across the corrugations).

Laboratory Testing

Frye et al (2012) also reported on testing to assess the impact resistance of a 0.48 mm thick metal corrugated cladding profile; the profiles were a corrugated profile and a square-rib profile. The cladding was installed in a 900 mm triple span arrangement using two sheets (to incorporate a side lap) and fixed to Z15015 purlins. The cladding was installed in roofing configuration, i.e. crest fixed to every second corrugation with the use of cyclone caps for high wind applications.

The threshold failure impact velocity of the corrugated cladding was found to be around 25 m/s when the cladding was impacted adjacent (within 100 mm) to an internal support with the 4 kg timber missile. When the impact took place at midspan, i.e. halfway between supports, the failure threshold velocity increased to about 29 m/s. Figure 4 shows two photographs of a wall sample that had been impacted at the same velocity of about 25 m/s but at different locations. As shown in Figure 4, the midspan impact is considered a pass, but the test with the impact adjacent to the support considered a fail.

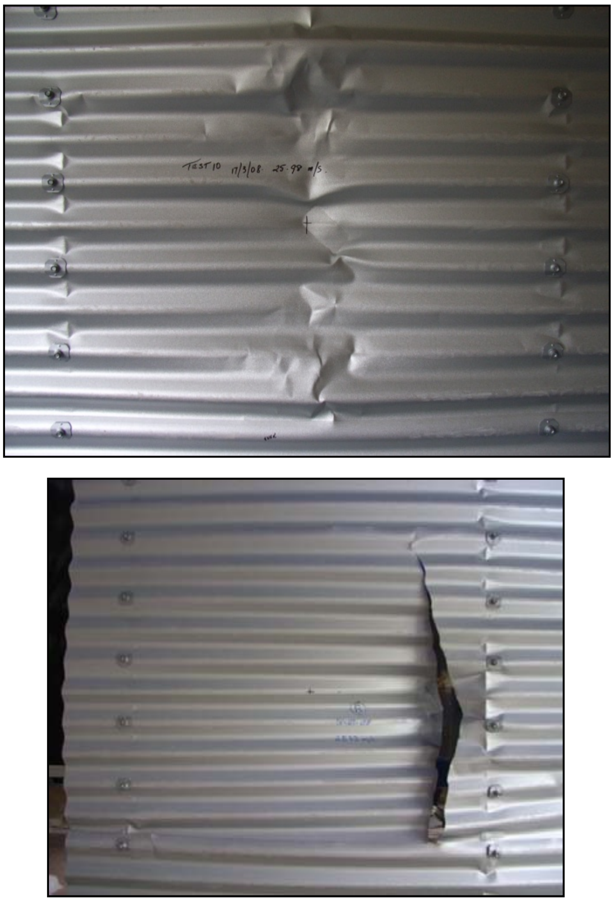

Figure 4. Corrugated wall cladding after impact at midspan (top) and close to internal support (bottom) by the 4 kg timber missile at 25 m/s. (Frye et al, 2012)

The cladding deformation suggests that the cladding absorbs the missile's kinetic energy up to a threshold velocity, beyond which the material's local shear strength is exceeded, resulting in failure.

These impact test results indicate that the critical location for impact testing of metal cladding is usually adjacent to the supports, rather than at midspan.

Structural Insulated Panels (SIPs)

It is difficult to establish generic threshold impact velocity values through empirical dynamic testing, as the variety of internal and external skin thicknesses varies significantly between products. Another factor that compounds the issue is the different joint connection mechanisms. Tests have shown that in conventional SIPs, the critical impact location can either be next to the panel joint or adjacent to the support. Tests shown in Figure 5 and Figure 6 had similar impact velocities and show typical impact damage; both tests were considered as a marginal pass.

Figure 5. Impact location adjacent to support: front view (left); rear (right).

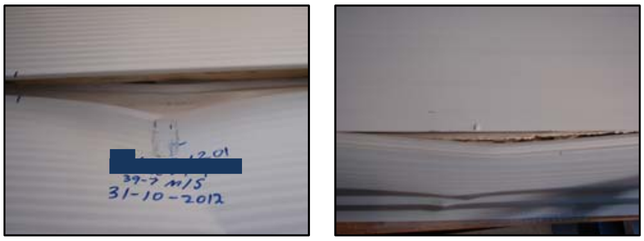

Figure 6. Impact location next to panel joint: front view (left); rear (right).

Recently, some SIPs manufacturers have been exploring innovative technologies aiming for high ductility, a principle that is commonly utilised in seismic engineering. It was found that high ductility enables a noticeable shift of the critical impact location and also allows higher impact velocities. A high ductility increases the energy dissipation capacity and shifts the critical impact location next to the panel joint. Tests shown in Figure 7 and Figure 8 had similar impact velocities and show typical impact damage; both tests passed but the one next to the joint was marginal.

Figure 7. Impact location adjacent to support: front view (left); rear (right).

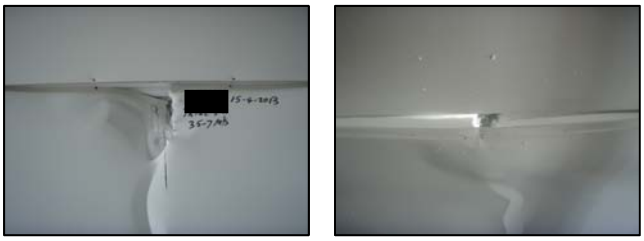

Figure 8. Impact location next to panel joint: front view (left); rear (right).

Garage Doors

The recent release of AS/NZS 4505:2012 and its inclusion in the BCA 2013 brought about a rush to get garage doors impact tested.

As has been noted for SIPs, the variety in curtain thicknesses and the different wind lock mechanisms makes establishing generic threshold impact velocity values through empirical dynamic testing, difficult. Tests shown in Figure 9 and

Figure 10 had similar impact velocities and show typical impact damage; both tests passed but the impact next to the joint was marginal.

Figure 9. Impact location adjacent to support: front view (left); rear (right).

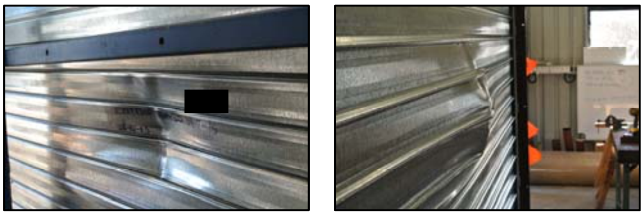

Figure 10. Impact location next to panel joint: front view (left); rear (right).

Comparison of Likely Critical Impact Locations

For the three building products considered (i.e. conventional metal cladding, SIPs, and garage doors) this paper demonstrates that they often have different critical impact locations. Table 1 is a summary table that compares which of the three common impact target locations is likely to be critical.

	Likelihood of Critical Impact Location		
	Midspan	**Adjacent to Support**	**On or Next to Joint**
Metal Cladding	rarely	predominantly	sometimes
SIPs (low ductility)	rarely	often	often
SIPs (high ductil.)	rarely	sometimes	predom.
Rolling Shutter Doors (incl individ. Slats)*	rarely	predominantly	rarely

*Assessed on limited available testing data to date

Table 1. Comparison of likely critical windborne debris impact locations.

Conclusions

Here we demonstrated that testing on SIPs and garage doors and demonstrated by Frye et al (2012) for metal cladding the midspan target location is rarely critical. This response is postulated to be caused by the larger deflection under impact at the centre of a span being able to absorb more of the missile's kinetic energy before the material's local shear strength is exceeded, which results in failure. For impacts close to the support, the cladding is restrained from deflecting and deforming plastically due to the stiffness introduced by its connection to the support (exception where innovative technologies which increase ductility are employed). It is postulated that adjacent to the support, the increased stiffness of the cladding causes larger impact reaction forces which then result in the cladding failing at a lower (and hence critical) missile impact velocity.

As buildings with an envelope that is deemed impact resistant can be designed to significantly lower design wind loads, testing is often conducted to demonstrate compliance. However, it is concerning that no regulatory documents currently exist to specify the testing requirements. This allows a worrying trend to continue, that sees many building products being tested using a single midspan impact trial. For most building products this impact location has a rare chance of failure compared to other locations. Therefore, additional impact locations should be targeted during testing to ensure that the critical one is included, using Table 1 as a guide, until more definitive information becomes available.

Acknowledgments

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