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Use of static tests for predicting damage to cladding panels caused by storm debris

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ABSTRACT

The impact by debris can result in extensive damage to building facades and roof coverings in extreme climate conditions such as windstorms and hailstorms. Damage can be in the form of denting on the surface of a metal cladding panel, which is controlled by the amount of force developed at the point of contact between the debris object and the surface of the panel. Amid the lack of guidelines for assessing damage to the building envelope, it is common to conduct impact tests on a cladding specimen. Such tests often involve the use of a gas gun to fire projectiles; however, there are shortcomings with this approach as it is mostly undertaken to check compliance and to observe permanent damage to the specimen. This paper presents the use of quasi-static tests to simulate the impact induced damage to metal cladding in storm scenarios. The contact force value generated during the impact action is predicted using the two-degree-of-freedom system model so that the impact action can be applied in a quasi-static manner on an MTS machine to predict damage in the form of indentation or perforation. This experimental technique for predicting damage is illustrated and verified in this paper by conducting confirmatory impact experiments. The risk of damage to metal cladding caused by impact in storm scenarios could then be assessed with confidence without having to conduct repetitive impact testing involving accelerating projectiles onto specimens of metal cladding. This research provides designers with an accurate and cost effective means of quantifying impact induced damage on building facades, and allows system developers to adapt and utilise existing and new materials to develop innovative solutions for withstanding impact.

1. Introduction

Windborne debris and hailstones can cause substantial damage to roofing tiles and metal cladding in extreme weather conditions [1–4]. Metal cladding can be dented or perforated by the impact of windborne debris. The consequences of damage of this nature can be the ingress of water into the building during a storm or permanent deformation of the building envelope that jeopardises its appearance. The total cost of replacing damaged components in the aftermath of a severe storm affecting a major city can amount to millions of dollars. In Australia, for example, the cost of damage caused by windstorms (e.g. about AUD 500 M in Queensland, Nov. 2008) or hailstorms (e.g. AUD 250 M in Melbourne Dec. 2011) can exceed tens of millions of dollars.

The modelling of the risk of debris generated damage in a storm scenario involves modelling (i) the disposition of debris (surrounding the building structure) that can potentially become windborne in stormy conditions as the first step; (ii) the trajectories of individual debris particles that depend on the elevation of the debris source, distance between the source and the target, and the wind speed as the second step; and (iii) the performance of the target (e.g. Cladding panel) for given impact conditions as the third step [3,5]. It is the third step of the modelling process that is the subject matter of this paper.

At present, the impact resistance assessment of a particular installation in response to impact action is normally determined by one or a combination of three different methods. The first involves costly pass/fail prototype experiments, such as impact experiments using a drop hammer or gas gun, to accelerate specific impactor objects at the surface of a target. Although this type of testing is common, it is mostly undertaken to check compliance and to observe permanent damage to the specimen, and is seldom performed repetitively to model variability [6–8]. Given that it is specific to the impact scenario and target sample employed in the test setup, the information obtained from physical experimentation is very restrictive. Consequently, little is known about the damaging potential of projected impact scenarios. Furthermore, not

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all laboratories are equipped with drop hammers or gas guns to facilitate such impact experiments. These limitations with the current techniques are major obstacles to the development of an effective and reliable approach to disaster mitigation during the service life of a building [6,7]. The second method utilises numerical simulations [1,9], which, although common, are seldom adequately validated by comparison with measured data from physical experimentation or by the third method, which involves overly simplified calculations based on treating the impact action as an equivalent static force. In summary, to date, no reliable method has been developed to accurately quantify the impact action of debris and the damage caused. These difficulties in predicting damage present a challenge to any attempt to improve the design or manufacture of components to achieve better resilience in future storm events.

In this study, the deflection demand of the impact by a piece of debris is first determined. The equivalent static force is then identified as the force that would produce a similar amount of deflection in the target (emulating the impulsive action of the impact). It should be noted that an equivalent static force based on the principle as described only emulates the impulsive action of the impact (which controls the global deflection of the target) and not the contact force. The impulsive action of the impact involves the inertia of a substantial region of the target plate while the much higher contact force involves the inertia of the local contact region only. The contact force lasts for a matter of a few milliseconds whereas the deflection of the target lasts for a much longer duration.

In the assessment methodology proposed in this paper, the parameters characterising the impact behaviour of the debris materials need to be identified. These parameters are the mass of the debris projectile, the velocity of impact, the stiffness parameters of the debris materials, and the coefficient of restitution for a given impact velocity. It should be noted that, in this study, it is assumed that the projectile debris has uniform velocity. Given the value of these parameters, the maximum contact force generated by the impact can be predicted. A test rig can be used to apply the estimated contact force to the target to ascertain the impact generated damage. The key objectives of this paper are to present experimental evidence in support of this approach to damage estimation by demonstrating that the state of damage to the target subjected to the impact test and the static test are nearly identical.

As described in earlier publications by the authors, impact experiments have been conducted on specimens of hailstones and a range of potentially windborne debris materials. The purpose of conducting such experiments was to obtain the “contact forcing function” (i.e. the time-history of the contact force generated by the impact) for a given set of impact parameters including those characterising the hardness of the impactor specimen. Such forcing functions can be applied to a specimen of the cladding panel in a quasi-static manner using a testing machine that is able to simulate the high strain rate behaviour of the impact. This approach to damage estimation has the merit of alleviating the need to undertake repetitive impact testing involving accelerating projectiles onto specimens of the cladding with a range of velocities. Essentially, experimentation on the impactor (i.e. the debris) object in isolation of the target to determine the nature of the impact is decoupled from the quasi-static testing of the target to determine the nature and extent of the damage. This decoupled approach to testing results in enormous cost savings in predicting impact induced damage. Such savings result from the elimination of the need to setup the target for impact testing, and, also, the generalised use of impact test results and the derived forcing functions enables the damage to a diverse range of installations, including trial installations of new designs or new building materials, to be predicted.

2. Global deflection estimates

The global deflection of the installed element and the local indentation on a metal surface are the two main types of damage assessment considered in this paper (Fig. 1).

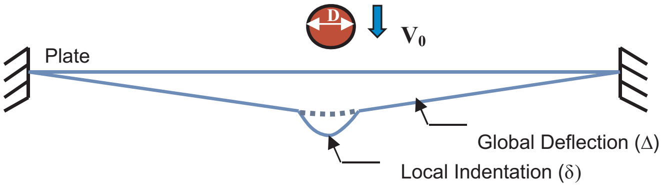

Fig. 1. Deflection profile of a target in the course of an impact.

A common calculation method based on energy principles, such as Eq. (1) [10], can be used to quantify the impulsive effect of the impact controlling the deflection demand (as opposed to the contact force controlling local indentation).

$$\Delta = \beta\frac{m_1 v_0}{\sqrt{m_1 k_2}}\ where\beta = \sqrt{\alpha\left[\frac{1+COR}{1+\alpha}\right]^2}\ \alpha = \frac{m_2}{m_1} \tag{1}$$

where m_1 is the mass of the impactor; m_2 is the effective mass of the target; k_2 is the stiffness of the target; v_0 is the incident velocity; α is the mass ratio; and COR is the coefficient of restitution. An equivalent static force can then be applied to the target to generate deflection that matches the estimate from the equation. It should be noted that the equivalent static force defined in this manner (based on the equal momentum and equal energy principles) should not be confused with the much higher contact force experienced by the surface of the target in contact with the debris impactor that causes local indentation or perforation.

3. Local indentation estimates

A common form of damage to metal cladding in a storm is denting on the surface. Advanced finite element codes, such as LS-DYNA and ABAQUS, can be used to simulate localised impact-induced damage. However, there are uncertainties concerning the parameter values for input into the analysis for characterising the dynamic properties of the impactor (debris) object. Unfortunately, little is known of the hardness properties of debris materials, which are vital for an accurate assessment of the nature of the impact. Such limitations in the current assessment methodologies are a major obstacle to the development of an effective and reliable approach to model the risk of damage incurred by the impact of debris in windstorms and hailstorms.

3.1. Measurement of contact force

The impact force generated at the point of contact between the impactor and the surface of the target is not to be confused with the equivalent static force, F, which emulates the impulsive effects of the impact (where $F = k_2\Delta$ forming part of Eq. (1), as presented in an earlier section of this paper). The amount of force experienced at the point of contact can be much higher than the quasi-static force because of the inertial resistance generated within the target [11]. There is limited documentation concerning methods to assess the impact induced localised damage to metal targets and the correlation of the extent of damage to the contact force value. This lack of knowledge concerning the contact force and localised damage is largely due to the difficulty regarding their measurement. The authors, who were inspired by the aforementioned knowledge gap described, set out to custom build a contact force measurement device in which the impactor is made to strike a lumped mass target that has been instrumented to track the acceleration and deflection of the supporting spring (Fig. 2). The contact force can be calculated as the summation of the reaction force (deduced from the retraction of the rear spring, which is measured by a laser sensor) and the inertia force generated from within the targeted object (deduced from the acceleration of the lumped mass, which is measured by the attached accelerometer). A full description of this new