International Journal of Impact Engineering 91 (2016) 126–141

Contents lists available at ScienceDirect

International Journal of Impact Engineering

journal homepage: www.elsevier.com/locate/ijimpeng

Deterministic solutions for contact force generated by impact of windborne debris

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ARTICLE INFO

Article history:
Received 22 October 2015
Received in revised form 9 December 2015
Accepted 5 January 2016
Available online 19 January 2016

Keywords:
Impact
Windborne debris
Contact force
Dynamic compressive stiffness

ABSTRACT

Impact by windborne debris can cause severe and wide spread damage to building facades and other exposed installations. There is no clear guidance on how to estimate the amount of force generated by the impact of windborne debris when design codes of practices only provide estimates of the wind pressure. The model presented in this paper enables the value of the peak contact force generated by the impact of a piece of debris to be predicted. Results of calculations employing the derived relationships have been verified by comparison with experimental results across a wide range of impact scenarios. Once the impact action has been quantified the predicted impact force can be applied to the target in a quasi-static manner for predicting damage.

1. Introduction

In extreme weather conditions such as windstorms, impact by debris has generated a great deal of damage to building facades. In addition to the effect of wind pressure [1], impact actions of storm debris should have been factored into the design of facades in exposed locations. In Australia, the damage bill of a windstorm can be up to tens of millions of dollars (e.g. about AUD500 million in Queensland, Nov. 2008). In the Eastern United States hurricanes in one year alone (2005) resulted in a damage bill totalling US$100 billion. The practical, and economical, approach of managing risks associated with windstorm hazard is to quantify risks, and to reduce the identified risks through adopting selective protective methods. Impact by windstorm debris has been identified as a major cause of damage to building facades including roofs, doors, and window shutters. Glass facades and metal claddings are most vulnerable to damage [2]. An effective mitigation measure to reduce risks of damage in a storm is to provide extra protection to windows [3]. The failure of corrugated panels, and composite insulated panels, against windborne debris impact have also been studied [4–6].

Sophisticated finite element software packages such as LS DYNA, ABAQUS, and ANSYS have been employed in the literature [5,7–11] to simulate damage by impact actions to circumvent the need of costly impact experimentation. However, the ability of the model to accurately simulate impact scenarios is often uncertain. Much of the uncertainties are related to parameter values for input into the impact analysis for characterising the dynamic properties of the impactor and the target. Impact fragility curves for storm panels have also been developed by the use of experiments and stochastic finite element models [7,12] to study the effects on building facades of debris impact. In summary, research into impact by windborne debris as reported in the literature [4–6,13–15] is mostly about observing, and simulating damage to specific types of targets as opposed to quantifying the impact action for a given impact scenario. Should a reliable predictive model for impact actions becomes available the estimated contact force could be applied in a quasi-static manner onto a finite element model at the point of contact for predicting damage to a diversity of target components. Essentially, the predictive model is to enable engineers to estimate the magnitude of the contact force with good confidence whilst circumventing the need to undertake impact experiments or impact dynamic analysis (which involves parameters of which the value can be difficult to ascertain for an accurate characterisation of the impact). An impact action can be resolved into the global deflection demand of the impact and localised contact force. The global deflection demand resulted from the impact can be estimated by equating momentum and energy [16] and can be emulated by what is known as an equivalent static force. In contrast, contact force is the force generated at the point of contact between the impactor and the surface of the target, and is much higher than the equivalent static force because of interferences from inertia forces generated within the target. Contact force lasts for only a few milliseconds whereas the deflection of the target evolves over a much longer period depending on the natural period of vibration of the targeted element. Contact force controls the amount of indentation into the metal cladding

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http://dx.doi.org/10.1016/j.ijimpeng.2016.01.002
0734-743X/

Fig. 1. Tested gravel specimens.

or the probability of perforation of glass. Thus, the magnitude of the contact force which is the subject matter of this paper is a critical piece of information for predicting damage.

The objective of this paper is to present the development of an analytical model for predicting the magnitude of the contact force as function of velocity of impact and the mass, and compression stiffness, of the impactor. A device was custom built by the authors for measuring contact force generated by an impact. Impact experiments were conducted on a range of impactor material in order that the analytical model can be verified. Details of the experimental investigation are first presented (Section 2). The non-linear visco-elastic model is then introduced to model the conditions of contact. Values of the parameters have been calibrated against experimental results. A rigid target was initially employed in the experimental investigation. Further tests were then conducted on a softer (aluminium) target to track the reduction in value of the contact force as the material properties vary.

2. Experimental investigation

2.1. Impactor specimens

An experimental investigation carried out by the authors involved impact testing of two types of gravel specimens: (i) gravels that had been machined into spherical objects and (ii) real gravels of random irregular shapes (Fig. 1). Experimental results show that the average contact force value generated by the impact of both types of specimens were very consistent provided that the values of relevant parameters characterising the impact (i.e. mass, impact velocity and material properties) have been kept constant.

It is shown that the contact force values recorded from individual impact tests varied considerably between specimens within the same sample of real gravels (Fig. 2). The observed scatter of results from experiments conducted on real gravels could be attributed to random variations in the geometry of individual gravel pieces. In

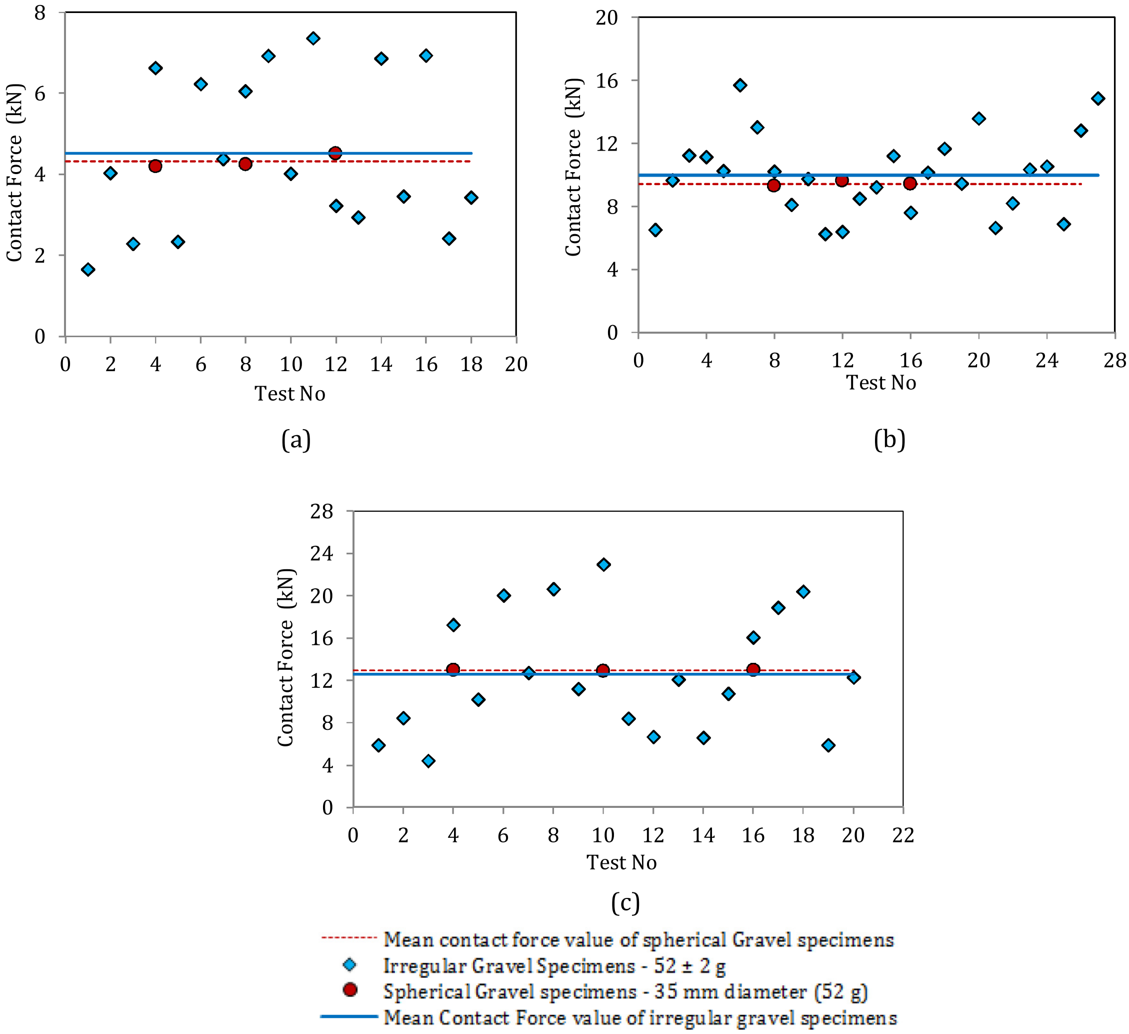

Fig. 2. Variation in peak contact forces generated by gravels at different impact velocities: (a) 5.4 m/s; (b) 11.4 m/s; (c) 15.4 m/s.