# ON HAIL DAMAGE TO BUILDING FACADES

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## ABSTRACT

Hailstorms are severe thunderstorms where most of the damage is done by hail. The damage caused by a severe hailstorm is considerable both in terms of money and human suffering. In this paper, an account of the on-going research on hail at CSIRO Building Construction and Engineering is provided. Research into hail characteristics, hail impact and severe storms is described. This work has culminated in the development of relatively simple analytical methods to predict damage due to hail impact.

## INTRODUCTION

Hail can create havoc and induce heavy losses. Large hail has been present whenever thunderstorm damage exceeded $10 million (Crane, 1989). Between 1982-92, hail damage in Australia resulted in insurance payouts in excess of $845 million. The Sydney hailstorm on 18 March 1990 caused a property damage (mostly to vehicles) of $320 million; a Brisbane hailstorm occurred on 18 January 1985 resulted in an insurance payout of $250 million for dented vehicles and smashed windows (ICA, 1993). The crop damage in Australia due to hail between 1985-92, was estimated to be about $128 million.

With the construction of more slender, tall and expensive buildings using light weight materials, hail is seen as a threat to the aesthetic appearance of these buildings. A hail damaged facade may cost 25% or more of the total cost of the building to replace.

Hail related damage (in dollars) is of the same magnitude as that of other natural calamities such as cyclones, earthquakes, floods and fires. Whereas rainfall has been systematically recorded for many decades, research into hail depends on sporadic reports by untrained observers. Until recently, the best source of information on hailstorms has been newspaper archives. Now, data gathering is highly dependent on "storm spotter" networks. A new Australia wide "hail spotter" network is being set up by CSIRO which will become operational in October 1994.

There are more than 1400 scientific papers on hail. These cover such topics as: hail suppression experiments, the early stages of hail formation, the radar reflection signature of hail, air movement inside thunderstorms, crop damage by hail, and insurance losses from hail. Little or no information is available in the sixteen key areas listed below:

- the statistics of the area of hailstorm footprints,
- the extreme statistics of hailstone size,
- a Standard for measuring hail damage,
- the effect of hail impact angle on hail damage,
- the relationship between hail energy and hail damage,
- the impact of the size of hail and age of the material hit on resulting hail damage,
- the near ground wind speed during hailstorms,

- the response of hailstones to the gustiness of winds,
- the frequency of hail occurrence around the world,
- the theory of hail impact on flat sheet materials,
- the variation of hailstone shape with size,
- the effect of hailstone shape on hail damage,
- the relationship between hail intensity and hail size,
- the effectiveness of hail protection devices,
- the relation between downdrafts underneath hailstorms and hail speed, and
- the energy loss by the hailstone due to shattering on impact.

More information on these key areas is required urgently. In this paper, a few of the above aspects are dealt with and recent advances made at CSIRO are described.

## RECENT DEVELOPMENTS

Some of the recent work conducted at CSIRO is summarised here. Using the NSW Bureau of Meteorology severe storms database, the relationship between maximum hail diameter and recurrence interval was obtained as shown in Figure 1. This information could be used for any location in Australia once the return period of 2 cm hail at that location is known.

In ASTM E822-81, the equation describing the terminal velocity (m/s) is given as $14.04 \sqrt{D}$, where $D$ is in cm. The horizontal velocity of a hailstone is governed by the horizontal wind speed. This simple formula agrees closely with some formulae derived by others. Experimental measurements of the terminal velocities of large hailstones at CSIRO have failed to confirm this equation but this lack of confirmation is probably due to the inaccuracy of the experiments.

The mean horizontal speed of a hailstone is very similar to that of the near ground wind speed in the thunderstorm in which the hail falls. When the thunderstorm duration is known, the return periods for thunderstorm wind speeds can be derived. AS1170.2 data for extreme winds in Region A are used. Region A is the non-cyclonic region, where thunderstorm winds dominate.

## DAMAGE PREDICTION

The theory of plate dynamics has recently been used to analyse hailstone impact on sheet materials and on idealised beams. The impact process of a hailstone striking a sheet or beam of material can be split into three main stages as shown in Figure 2.

In the first stage, as the hailstone strikes the material, local deformations, elastic and possibly plastic, occur near the contact area. The deformations last until the relative acceleration between the hail and the material is zero. An example of this stage is the impact of a rubber ball with a solid material. The Hertz law of contact could be used to carry out the analysis of this stage and gives the maximum deformations and pressures. The maximum load and deflection are concurrent.

In the second stage, the stress waves created by the impact process in the material travel away from the contact area, towards the edge of the material, and rebound. The stresses in the material are separated into bending (linear) and membrane (non-linear) stresses. The bending stresses expand much more slowly than the membrane stresses. This stage is analysed by assuming a generic axisymmetric deflected shape governed only by the two parameters of depth and radius. The load, acceleration and radius are calculated from a non-linear differential equation. The maximum load and deflection are not concurrent.

In the final stage, the material rotates about its supports. The deflected shape resembles to that of a statically loaded plate after relatively long time intervals. This stage is characterised by vibrations and mode shapes. It is analysed using methods similar to those of the second stage but is simpler because the radius is now constant. The maximum load and deflection are concurrent.

The expressions developed using the above theories and their applications have been illustrated by Paterson and Sankaran (1994). In these analyses, neither plastic deformation nor cracking (except in the initial energy loss due to hailstone cracking assumed in the second and third stages) has been taken into account. The development of better techniques, possibly using finite element methods, is desirable and will be considered in future.

## CURRENT WORK

Work is progressing on the sixteen areas listed earlier in this paper. Videos of hailstorms are being analysed to get an understanding of the hail characteristics. The hail impact process on building envelopes is being investigated using analytical, numerical and experimental methods. A high speed camera attached to an optical sensor is being used to capture details of the hail impact process. On impact, some energy is lost through stress wave expansion, plastic deformation and hail shattering. The details of hail shattering process will be needed in understanding the mechanism of plastic deformation or material cracking as these events occur concurrently.

## CONCLUDING REMARKS

The perils of severe hailstorms have been highlighted through examples of insurance loss estimates in this paper. Sixteen key areas that require detailed research are identified and listed. A brief description of some recent work at CSIRO which culminated in the development of hail damage prediction methods is given. Hail damage could be minimised and the basic design of building envelopes could be improved by using these methods for analysis.

## REFERENCES

Crane, G. (1989). "Severe Local Storms: Hail", Natural Hazards and Reinsurance, Oliveer, J. And Britton, N.R. (eds), Sterling Offices (Australia) Ltd., pp 29-44.

Insurance Council of Australia (1993), Private Communication.

Paterson, D.A. and Sankaran, R. (1994), "Hail Impact on Building Envelopes", to appear in *Journal of Wind Engineering and Industrial Aerodynamics*.

Standards Australia (1989), "AS1170.2 SAA Loading Code Part 2: Wind Loads".

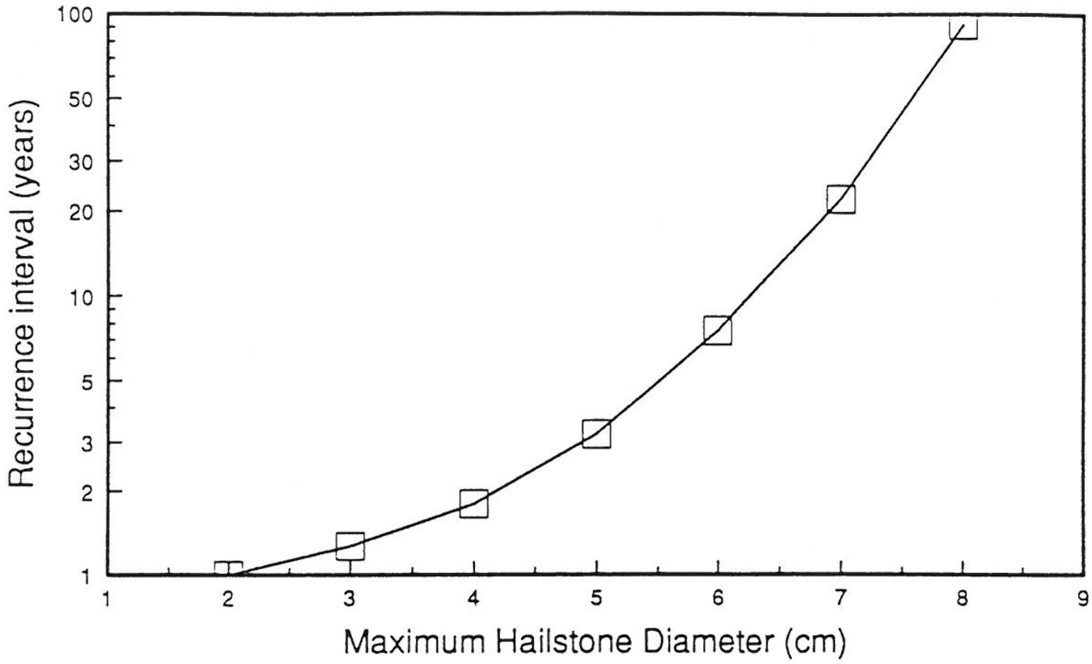


Figure 1 The recurrence intervals as a function of hail size

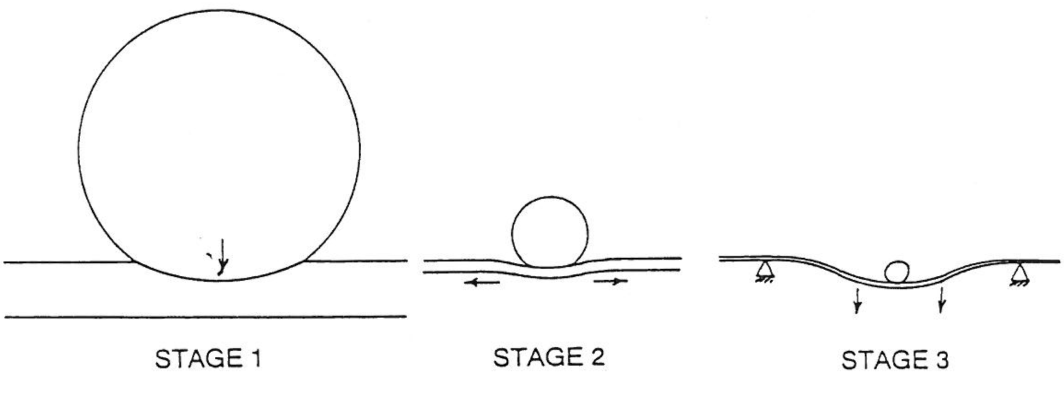


Figure 2 The three stages of hailstone impact; (1) Local deformation (2) Expanding stress waves (3) Quasi-static