PRACTICE NOTE NUMBER: 19	Version: 2	SEPTEMBER 2016 Updated: March 2022	Page 1 of 6
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Hail Loading on Roofs			

Introduction

The effect of loading on structures from hail storm events is not well accounted for under the current design provisions. There is no reference to designing for hail events in the Building Code of Australia. The commentary of the loading code (Section 3.5 AS/NZS 1170.1-2002) does outline a specific load case and design assumptions for the case of water ponding and local hail loading on roofs, and does not suggest the presence of hail will prevent rain water runoff.

On Saturday 25 April 2015 a significant hail storm event occurred in Huntingwood, Sydney that led to the significant structural failures of a number of warehouse buildings in the area. This practice note has been based on observations and analysis following investigations into the collapse of these buildings. Previous hail storm events have also been investigated and incorporated.

This practice note aims to provide structural engineers and the building industry with interim guidance for the application of hail loads on buildings, until such time that the Australian Standards are upgraded to take this loading scenario into account.

Occurrence of Hailstorms

Hailstorms are typically short in duration and vary in intensity. They occur within thunderstorms and are often associated with intense rainfall. There is a lack of accurate data relating to severe hailstorm events, and their recurrence intervals (Middelmann, 2007). Researchers have typically relied on eye witness reports.

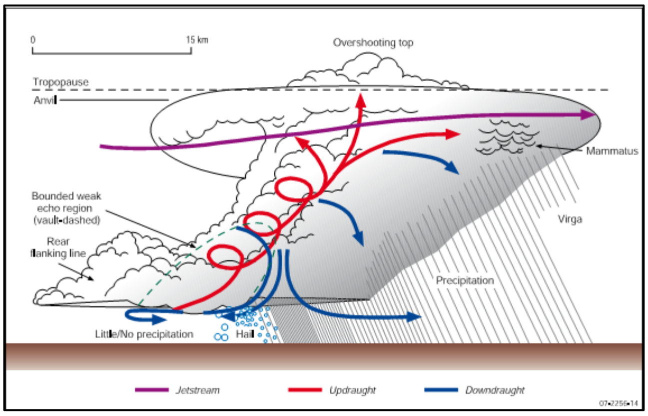


Figure 1: The Development of Severe Thunderstorms
Source: (Middelmann, 2007) *Figure 6.1*

Damage to buildings from hail either occurs as impact damage by large hail stones or from overloading due to a high volume of retained hail and rainwater. The 1999 Sydney hail storm which caused a large amount of damage to roofs and vehicles is an example of damage done by large hail stones. However, the loading scenario with a large amount of small hail stones (<20mm) combined with rain can exceed the current minimum code design requirements for non-trafficable roofs. This has led to the collapse of large structures supporting roofs. Examples of these storms occurred in Brisbane in 2005, Canberra in 2007 and Sydney in 2015.

The area east of the Great Dividing Range between southern Sydney and Brisbane is particularly susceptible to hail storms (Bednarczyk, 2014), recording approximately 10 hailstorms per year on average (Schuster, 2005). In this coastal region westerly cold fronts travel over the mountains and collide with moist warm coastal air. Through the phenomenon of orographic lift precipitation is pushing into the freezing zone as it passes over the mountain ranges resulting in hail.

Models studying the effects of climate change on storm occurrence toward 2030 and beyond indicate a there could be an increase in the number of hail-days per year along the south east coastline. (Middelmann, 2007)

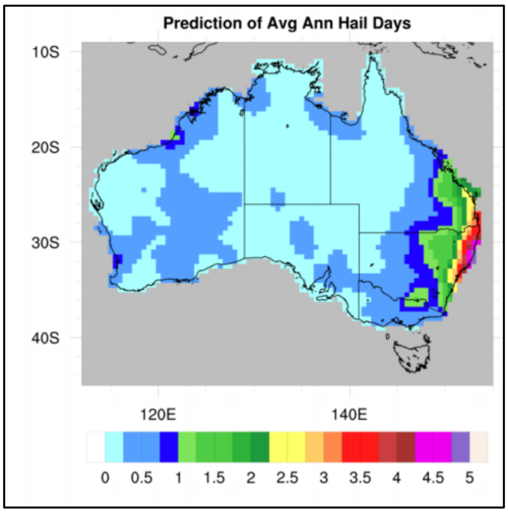


Figure 2: Prediction of Hail Days
Source: (Bednarczyk, 2014) *Section 4, Figure 6*

Properties of Hail

Hail Density

Although hail has a lower density than water (10kN/m^3), as hail thaws and becomes a mixture of ice and water the density increases and approaches the density of water. A reasonable assumed density of hail is 7.5 kN/m^3.

Figure 3 – Hail stones that fell on 25 April 2015 - Huntingwood, Sydney
Source: http://www.extremestorms.com.au/hail-drifts-western-sydney-25th-april-2015/

Hail Drift

Hail drift describes the local accumulation of hail falls. Hail drifts are typically caused by flowing rainwater runoff, high winds or obstructions and lead to the concentration of hail loads. Factors determining the amount of hail drift on roofs are the shallowness of the roof slope, the roof length, obstructions on the roof and the amount of rain falling around the time of the hail. As the co-efficient of friction of ice on steel is 0.03, or 1.72 degrees it is unlikely hail will slide down a roof on slopes less than 2.0 degrees. The reported depth of hail during the Huntingwood storm as a result of drift was between 100 and 500mm.

Figure 4 – Security camera footage of combined hail and rainfall causing hail drift. 25 April, 2015, Huntingwood, Sydney

Rainfall and Hail

The combination of rainfall and hail does change the loading pattern on the roofs of buildings. If hail was to fall without rain, it is unlikely that the hail would experience substantial slippage and movement down the roof. In this loading case there is a relatively uniform blanket hail loading applied to the roof.

In the case where there is also rain, the propensity of the hail to melt and slide down the roof increases. The hail on the roof also reduces the rate rainwater is able to run off shallow roofs and consequently leads to localised loading on the roof that is higher than a uniform blanket of hail. In addition, the overflow of rainwater through side laps in the roof sheets saturates the insulation beneath. The water held within the insulation significantly increases the loading on the roofs.

Collapse Mechanism of Hail on Large Shallow Sloped Roofs

The following section describes the likely failure mechanism of large, shallow sloped roofs under hail and rain loading.

Phase 1 – Uniform Hail Loading

Hail begins to fall onto the wet roof. The majority of the hail initially rests on the roof and accumulates in a uniform manner. It is likely that some of rainwater already on the roof would freeze into ice. The roof begins to deflect or sag in the mid span of the rafters, locally lowering the slope of the roof. Rain water, ice and hail then begin to build up on the roof.

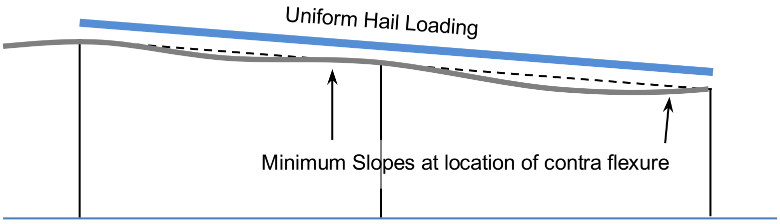


Figure 5 – Initial Hail Loading on Roof

Based on site observation of the 2015 Sydney hailstorm a 30mm to 50mm depth of hail on the roof is a reasonable assumption without considering hail drift. When the pans of the roof sheeting become full of hail as depicted in figure 6, an approximate equivalent uniformly distributed load (UDL) of 0.25 kPa could be assumed.

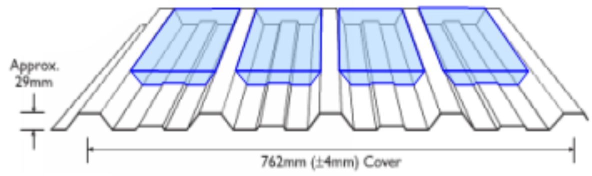


Figure 6 – Modified Image from Stramit Monoclad Technical Manual (Lysaght Trimdek Equivalent)

Phase 2 – Localised Hail Accumulation

During this phase there is a buildup of rain water and melting hail on the roof, deflecting the rafters under load and then the formation of the first plastic hinge. The buildup of water on the roof occurs where the roof is not able to discharge water. This would occur where the roof slope becomes too shallow under the weight of hail and ice, the box gutters become blocked or other obstructions.

Once the roof slope becomes less than approximately 2 degrees, hail, water and ice rapidly accumulates on the roof. Roof sheeting fixings may begin to fail and water leaks into the building between the sheeting laps. The loading predominantly accumulates on the end span of the rafter. This is due to a number of factors;

1. There is a higher volume of water on this part of the roof due to the length of upstream roof catchment;
2. The end spans of portals are typically less stiff than the internal span;
3. Once the end span deflects the deflection of adjacent span reduces and increases the slope of the internal span.

The loading is a combination of the blanket hail UDL and localised loading on the end spans as depicted in figure 7. The localised loading is a function of the tributary area of water runoff.

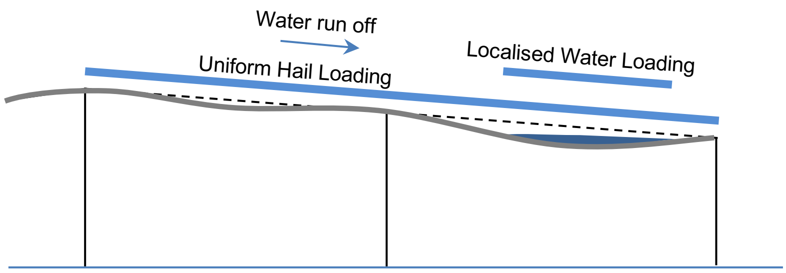


Figure 7: Accumulated Hail and Water Loading on Roof

Phase 3 - Building Collapse

Once the loading on the roof increases beyond the capacity of the rafter, plastic hinges begin to form. Typically two or three plastic hinges are required to form before a steel portal framed structure collapses.

The order of the formation of the plastic hinges varies from building to building and is largely academic. Typically, once the first plastic hinge is formed on the end span, the internal rafter spans and columns would begin to fail relatively quickly. The building then collapses in a ductile manner.

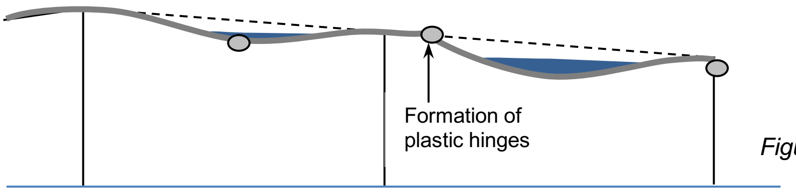


Figure 8 – Formation of plastic hinges leading to collapse

Figure 9 – Photographs of collapsed warehouses 25 April 2015, Sydney.

Recommended Loading on Roofs

A roof structure should be designed for hail loading where the roof pitch is less 5 degrees. It is recommended that structures located to the east of the Great Dividing Range between southern Sydney and northern Brisbane should be designed for hail loading. Hail loading on buildings outside this area should also be considered, depending on the local history of hailstorms.

The range of recommended hail loading be applied to roofs of structures in line with the importance level described in the BCA (part B1.2) and AS/NZS 1170.0 (Table 3.1).

TABLE 3.1

CONSEQUENCES OF FAILURE FOR IMPORTANCE LEVELS

Consequences of failure	Description	Importance level	Comment
Low	**Low** consequence for loss of human life, *or* **small or moderate** economic, social or environmental consequences	1	Minor structures (failure not likely to endanger human life)
Ordinary	**Medium** consequence for loss of human life, *or* **considerable** economic, social or environmental consequences	2	Normal structures and structures not falling into other levels
High	**High** consequence for loss of human life, *or* **very great** economic, social or environmental consequences	3	Major structures (affecting crowds)
		4	Post-disaster structures (post disaster functions or dangerous activities)
Exceptional	Circumstances where reliability must be set on a case by case basis	5	Exceptional structures

Extract of Table 3.1 from AS/NZS 1170.0 2002

Hail Loading on Roofs

Importance Level 1
Minor Structures.
No increase is recommended to AS/NZS 1170.1 loading requirements.

Importance Level 2
Normal Structures
Roofs with slopes greater than 3.0 degrees.

<u>Ultimate Limit states Design</u>
Live load (Q) for non-trafficable roofs be taken as the worst case of;

- The roof live load for non-trafficable be 0.25 kPa applied over the entire roof as a uniformly distributed load, or;
- A minimum pattern load of 0.25 kPa over 200 square meters is applied in accordance with AS/NZS 1170.1.

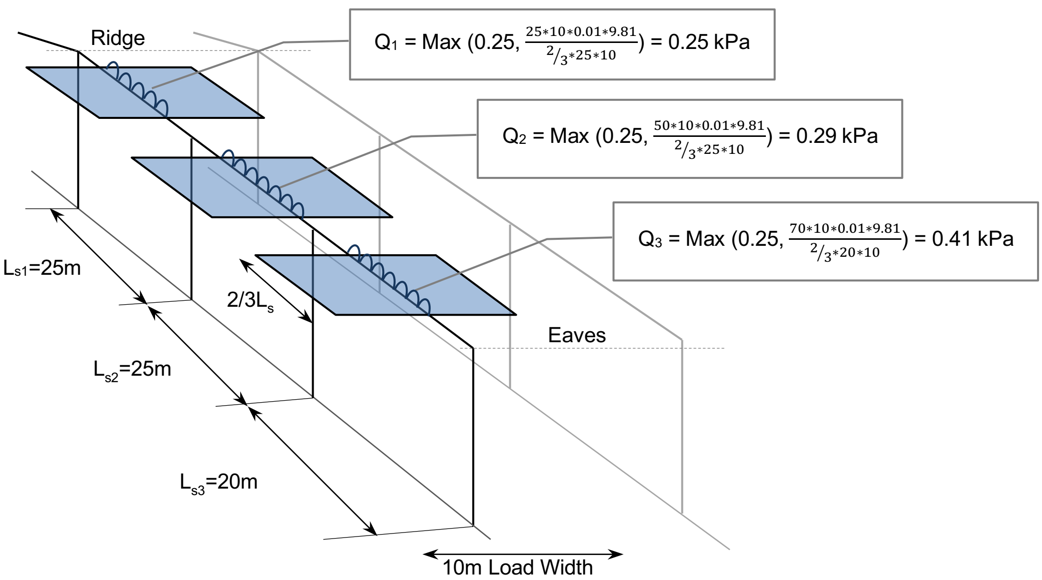
<u>Service Limit State Design</u>
The service limit state design objective under the hail loading scenario is to prevent the accumulation of rain water and hail on the end span of large roofs. The roof under the load case G + Q must not fall below 2.0 degrees or below 1 degree above the roof sheet manufacturers' 1 in 100 rainfall storm event minimum slope. This recommendation is in addition to the guidance in Appendix C of AS/NZS 1170.0.

Importance Level 3
Important or major structures.
All roofs where slopes are less than 3 degrees.

<u>Ultimate Limit states Design</u>
Live load (Q) is a <u>combination</u> of;

- The roof live load for non-trafficable roofs be 0.25 kPa applied over the entire roof as a uniformly distributed load and;
- A pattern load representing water and ice ponding on the roof member being the maximum of;
  - 0.25 kPa applied over 200 square meters in accordance with Section 3.5 of AS/NZS 1170.1 or;
  - A calculated pattern load of Q = $\frac{A_R.w}{2/3 L_s W}$ applied to the minimum of the central 2/3 of the span or 200 sqm, where;

    A_R = Total upstream roof rainfall catchment area (m^2) that would be supported by the structural member being analysed.
    w = The total weight of the rainfall to be supported by roof (m). A minimum rainfall of 10mm is recommended, and would depend on local ARI.
    L_s = Span of member being analysed.
    W = Tributary width of member being analysed.



- The hail loading applied to a purlin is extracted from the rafter loading as calculated above.

Service Limit State Design

The service limit state design objective under the hail loading scenario is to prevent the accumulation of rain water and hail on the end span of large roofs. The slope of the roof under the load case G + Q must not fall below 2.0 degrees or below 1 degree above the roof sheet manufacturers' 1 in 100 rainfall storm event minimum slope.

This recommendation is in addition to the guidance in Appendix C of AS/NZS 1170.0.

Importance Levels 4 and 5

Buildings with Post Disaster functions (hospitals, defence, power and water supply etc.). The loading for these buildings should be assessed in more detail and is outside the scope of this paper. As a minimum it is recommended that importance level 3 loading recommendations are adopted, combined with a roof slope greater than 3 degrees and an increase rainfall loading (*w*) be adopted.

Other Design Recommendations

Plastic Analysis	Plastic analysis and the adoption of plastic hinges in the design should not be adopted under the load cases described in this practice paper. However, a prediction of the formation of plastic hinges under these loadings should be made, and additional lateral restraint should be added to steel members to increase plastic rotation capacity.
Structural Robustness	In considering Section 6.1 of AS/NZS 1170.0, member continuity should be part of the design, to ensure that the structure fails in a ductile manner.
Connections	The moment capacity of bolted moment connections should be at least the member capacity of the weakest section being connected. This is to prevent non ductile failure.
Roof Slope	Increasing the roof slope is strongly recommended. The adoption of roof slopes below 3 degrees presents a significantly higher risk to ponding of hail and rainwater on roofs.
Roof Sheeting Material	A heavy gauge metal roof sheeting (minimum 0.48BMT) with a high runoff capacity be adopted. The manufactures rated roof slope for 100 year rainfall event should be 1 degree.
Roof Obstructions	Where possible roof obstructions should be reduced or eliminated. Any obstructions should be located to minimise the risk of ponding of hail and rain water. Examples of these obstructions include parapets, roof plant, solar panels and clip on walkways. Box gutters blocked by hail and ice caused a large amount of damage to buildings as they frequently blocked and subsequently allowed water to penetrate the building.
Gutters	Avoid box gutters all together. Hail blocks box gutters leading to significant roof leakage and potential structural; overload conditions. Hail guards are recommended on eave gutters.
Purlin Spacing	Purlins should be spaced at a maximum of 1500 ctrs to minimise localised sagging of the roof sheeting.
Purlin Stiffness	Adjacent purlins should deflect under hail loading so that the minimum recommended roof slope nominated above is maintained. Particular attention should be paid to comparing the deflections of the stiffer eaves purlins to the more flexible internal purlins.

References

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