Can we build disaster resilient communties?

A new look at wind effects on houses

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A new look at wind effects on houses

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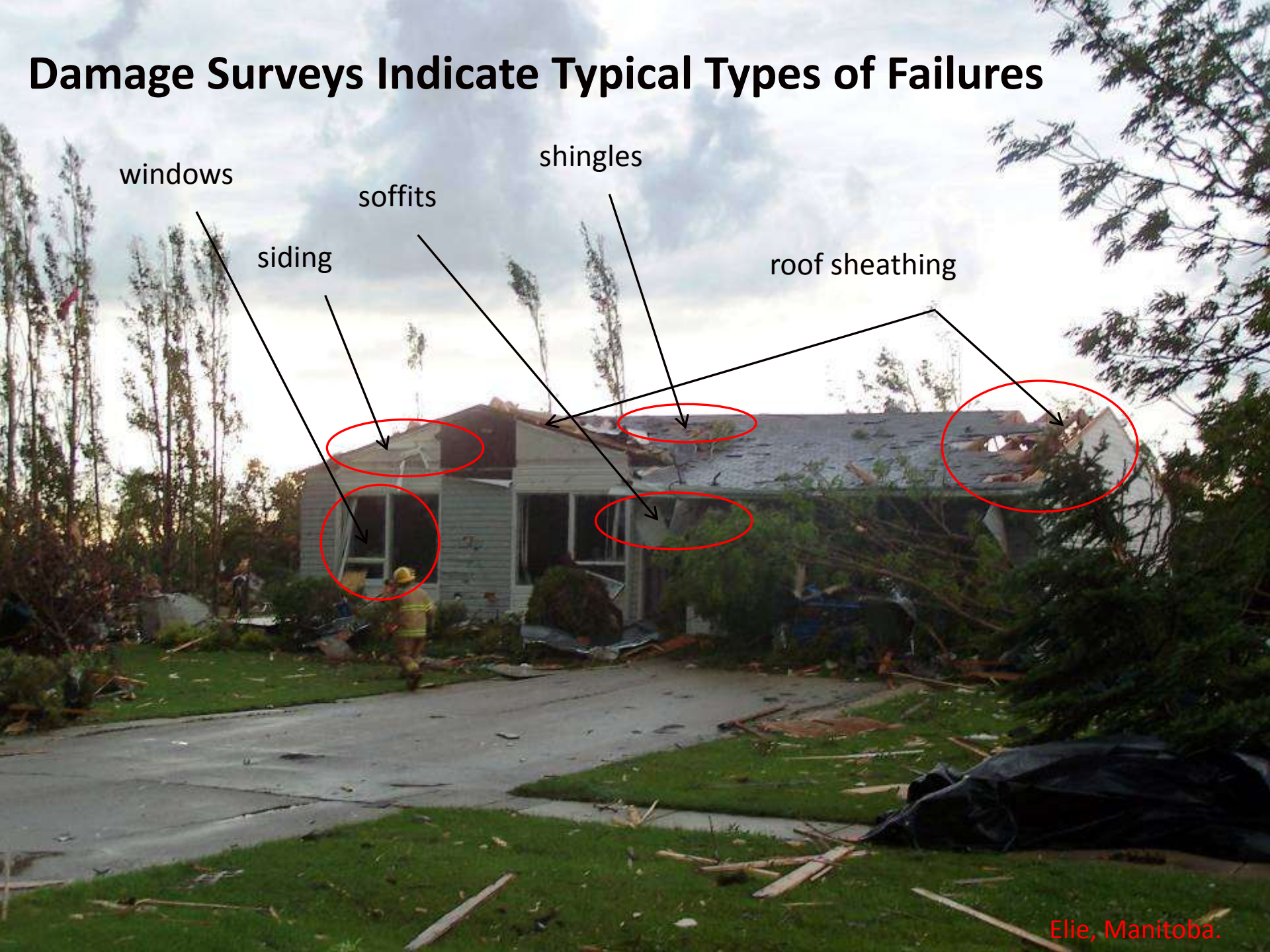
Objectives of Presentation

- What's the problem? Overview of typical wind damage from recent storms
- Roof issues
- Wind-borne debris
- Full-scale lab testing
- Wind tunnel testing
- Discussion about mitigating wind damage

Damage Surveys Indicate Typical Types of Failures



Hurricane Ivan, Florida panhandle, 2004

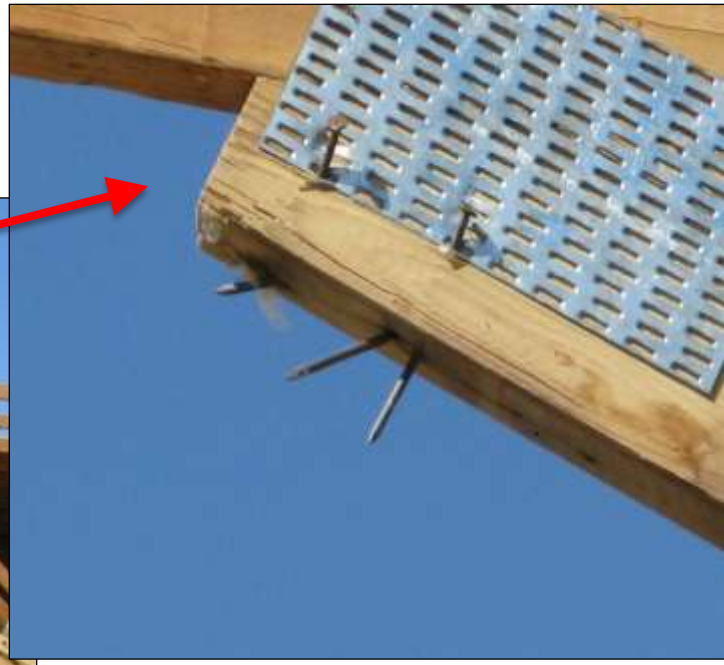
Roofs are particularly vulnerable to wind loads… the loss of a single roof panel can lead to significant contents damage

Rain water entry is a major cause of losses

Significant water damage with second floor roof failure – water down to the first floor.

Global roof failure of toe-nailed connections

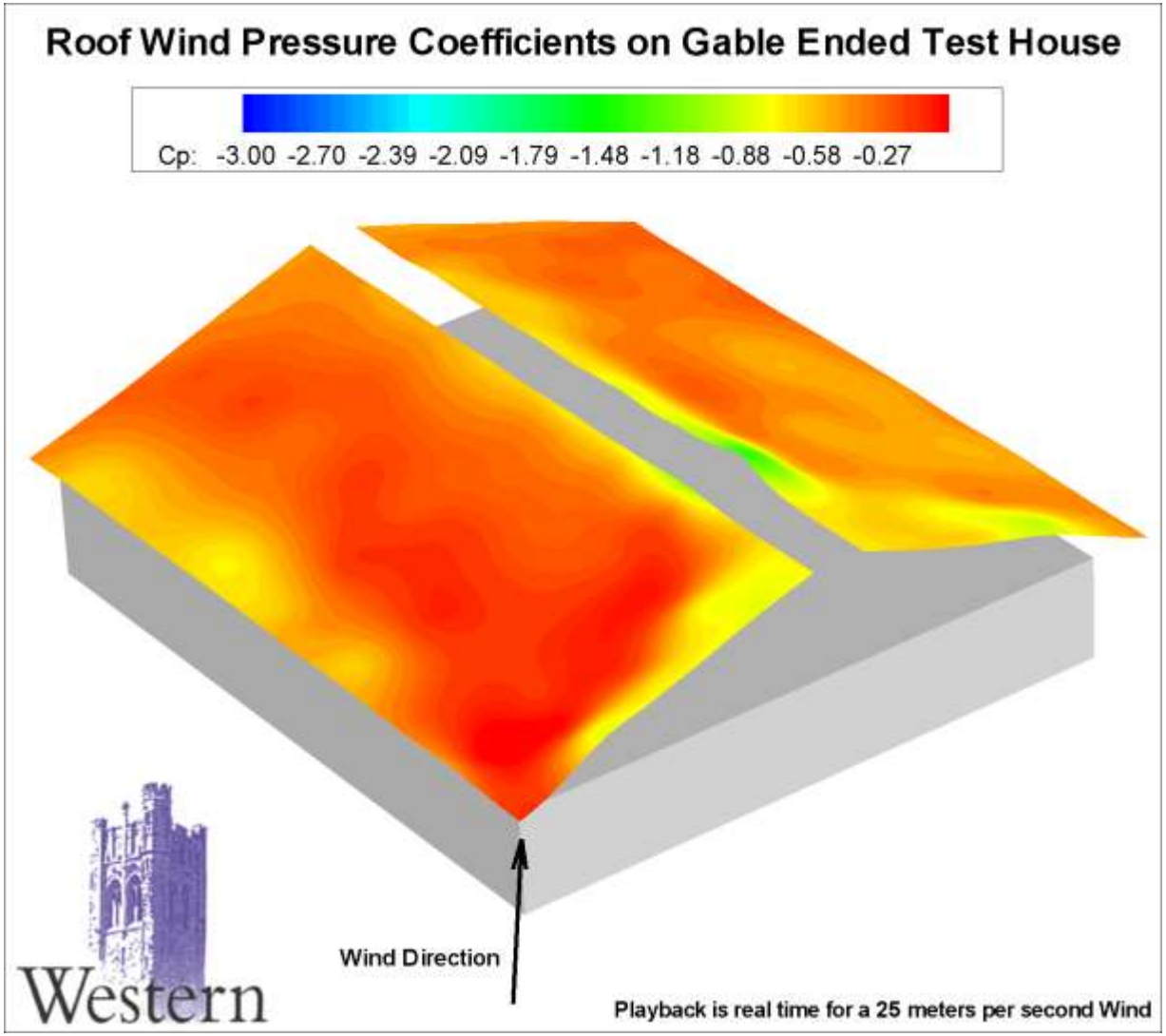
Roofs are vulnerable to uplift.
Nails, which hold the roof done, are very important to how houses perform



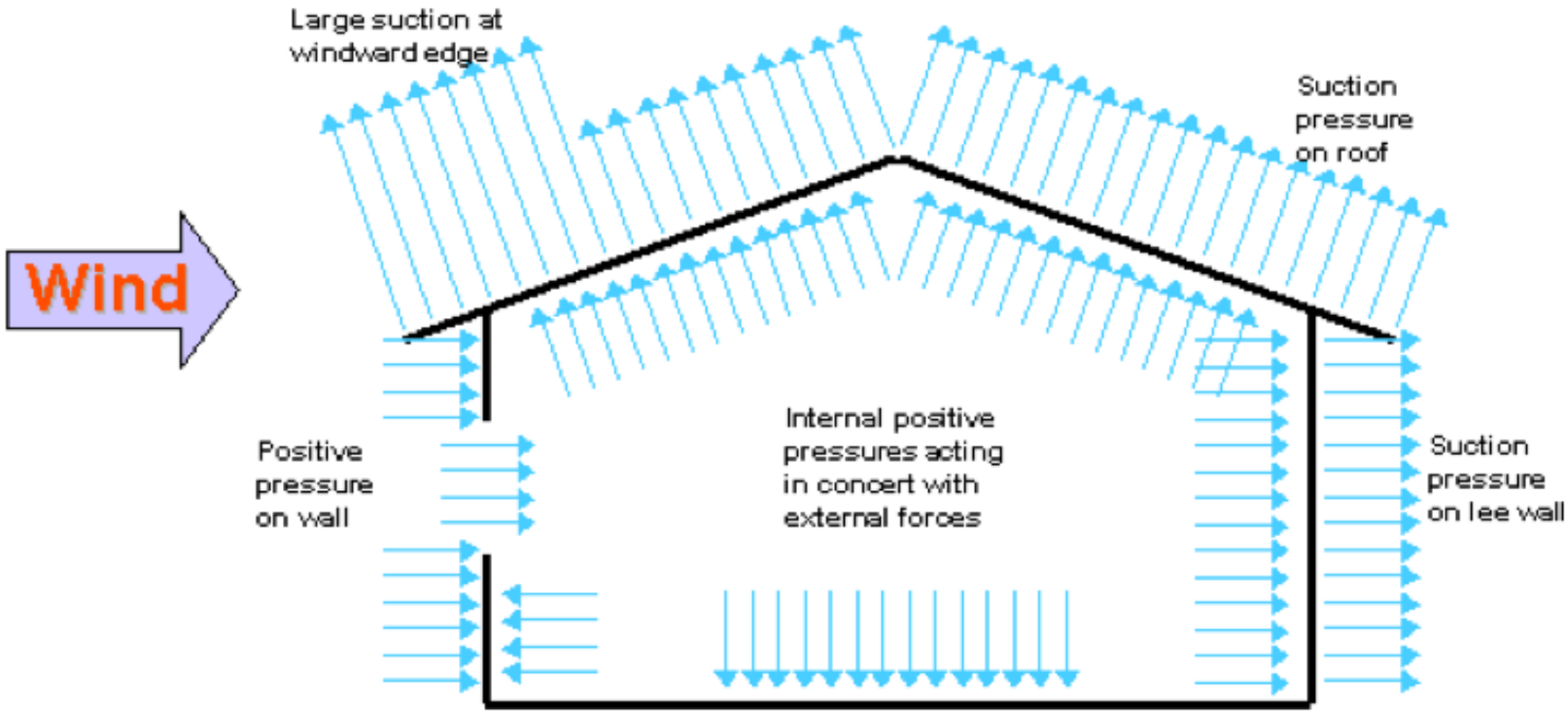
WHY ARE ROOFS VULNERABLE:

Imagine turning a house upside down…
hanging weights off the roof…
and shaking it…

Wind Induced Pressures on the Roof of a House



Internal Pressurization, due to failures of wall components, often leads to roof failures



Peak internal pressures depend on several parameters…basically the positive wall pressure is transferred into the interior volume

Large windward wall opening – internal pressurization – roof failure

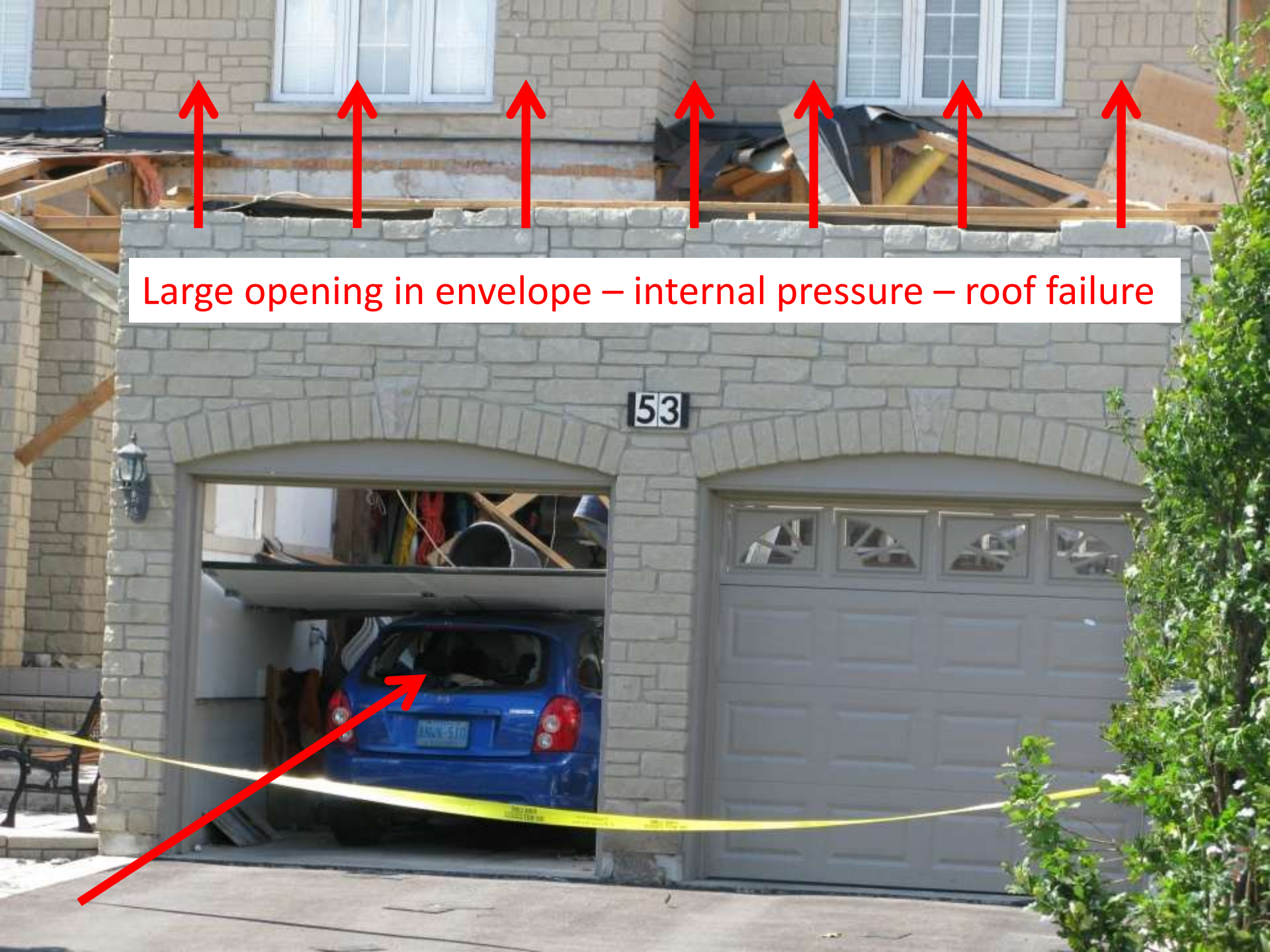
VAUGHAN, 2009

These were the correct nails… but there are only 2, not 3

VAUGHAN, 2009

The neighbour's house… very minor shingle damage

VAUGHAN, 2009


Large opening in envelope – internal pressure – roof failure
53

VAUGHAN, 2009

Total Roof Failures

Table 4. Damage statistics from the Vaughan tornadoes pertaining to wind-borne debris

Scenario	# of Houses (%)
Breaches of building envelope (walls, windows, garage doors)	35 out of 92 (38)
Houses with dominant openings	20 out of 92 (22)
Dominant opening & damage of any kind*	17 out of 20 (85)
Dominant opening & major roof damage	14 out of 20 (70)
GARAGE DOORS	
Dominant openings due to garage doors	17 out of 20 (85)
Major roof damage due to dominant openings from garage doors	11 out of 17 (65)
Damage of any kind due to dominant openings from garage doors*	14 out of 17 (82)

* only damage that would be affected by internal pressures is considered

Total Roof Failures

Angus, 2014….7 houses in row!

Internal pressures do not seem to have played the same role as they did in the two 2009 Vaughan tornadoes because of the wind directions involved.

ANGUS, 2014

Total Roof Failures

Total Roof Failures

Incorrect toe-nailed, roof-to-wall-connections were prevalent

Structural Roof Failures

Lab tests of toe-nailed connections

Our preliminary analysis suggests that 2 missing nails per connection reduces the failure inducing wind speed by about 40%

Roof truss

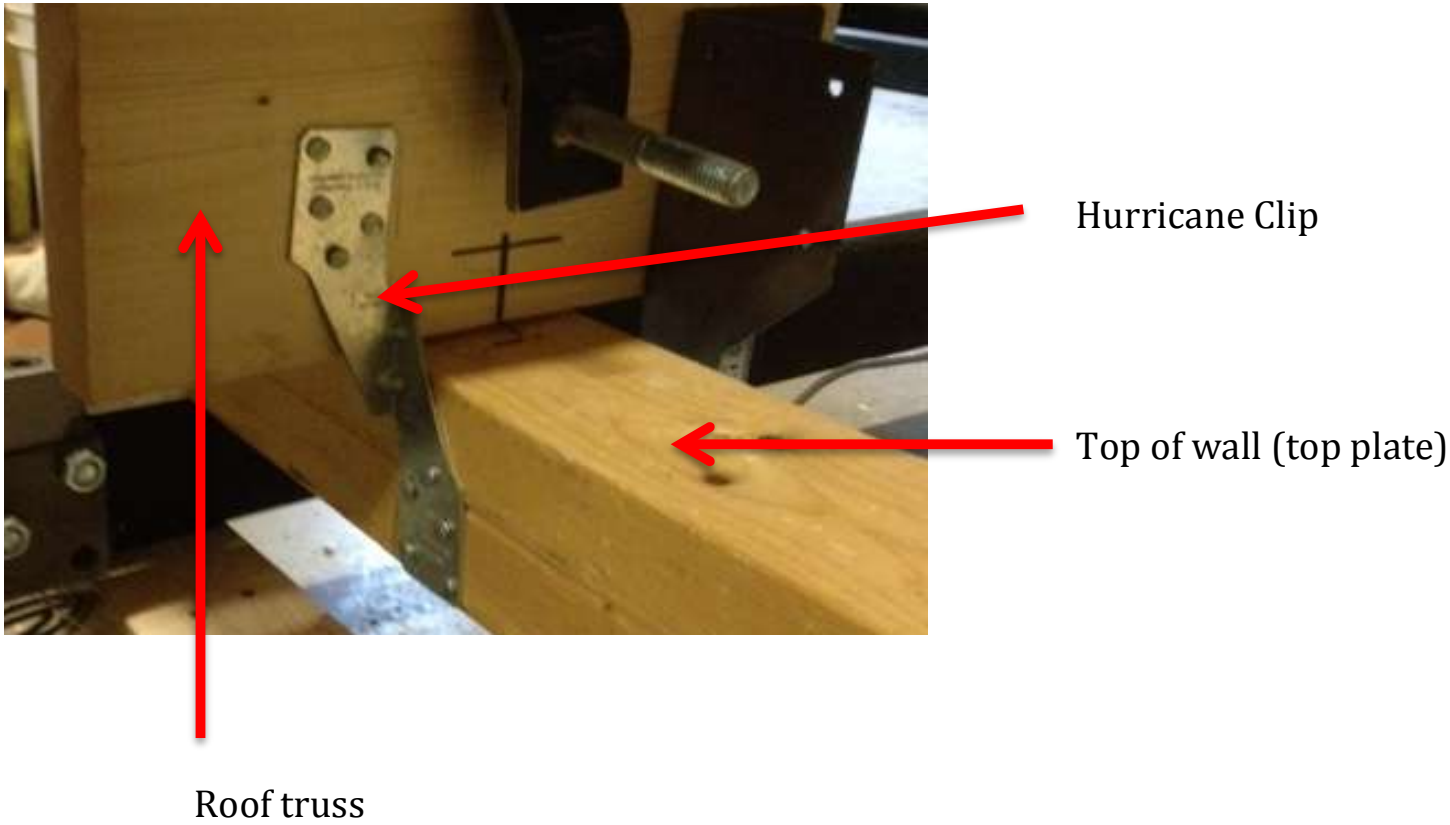
A toe-nailed connection (after withdrawal from top plate in lab test).

The building code requires 3 nails to connect each roof truss to the top plate of the walls.

Top of wall (top plate)

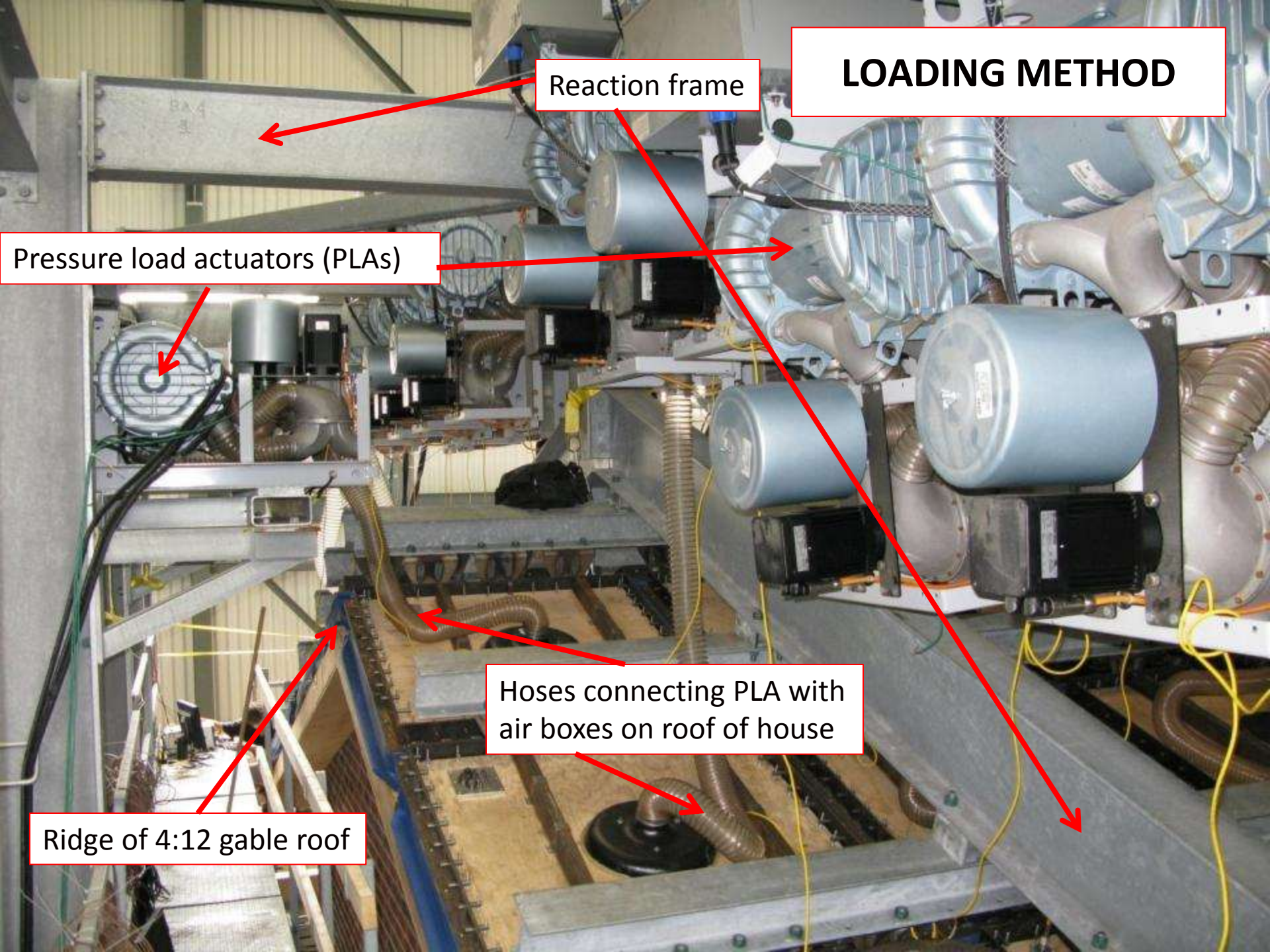
Structural Roof Failures

In contrast, inexpensive hurricane clips roughly double the capacity. **Our analysis of the Vaughan Tornado suggests that these would have kept the roofs on in these events, even with dominant openings.**

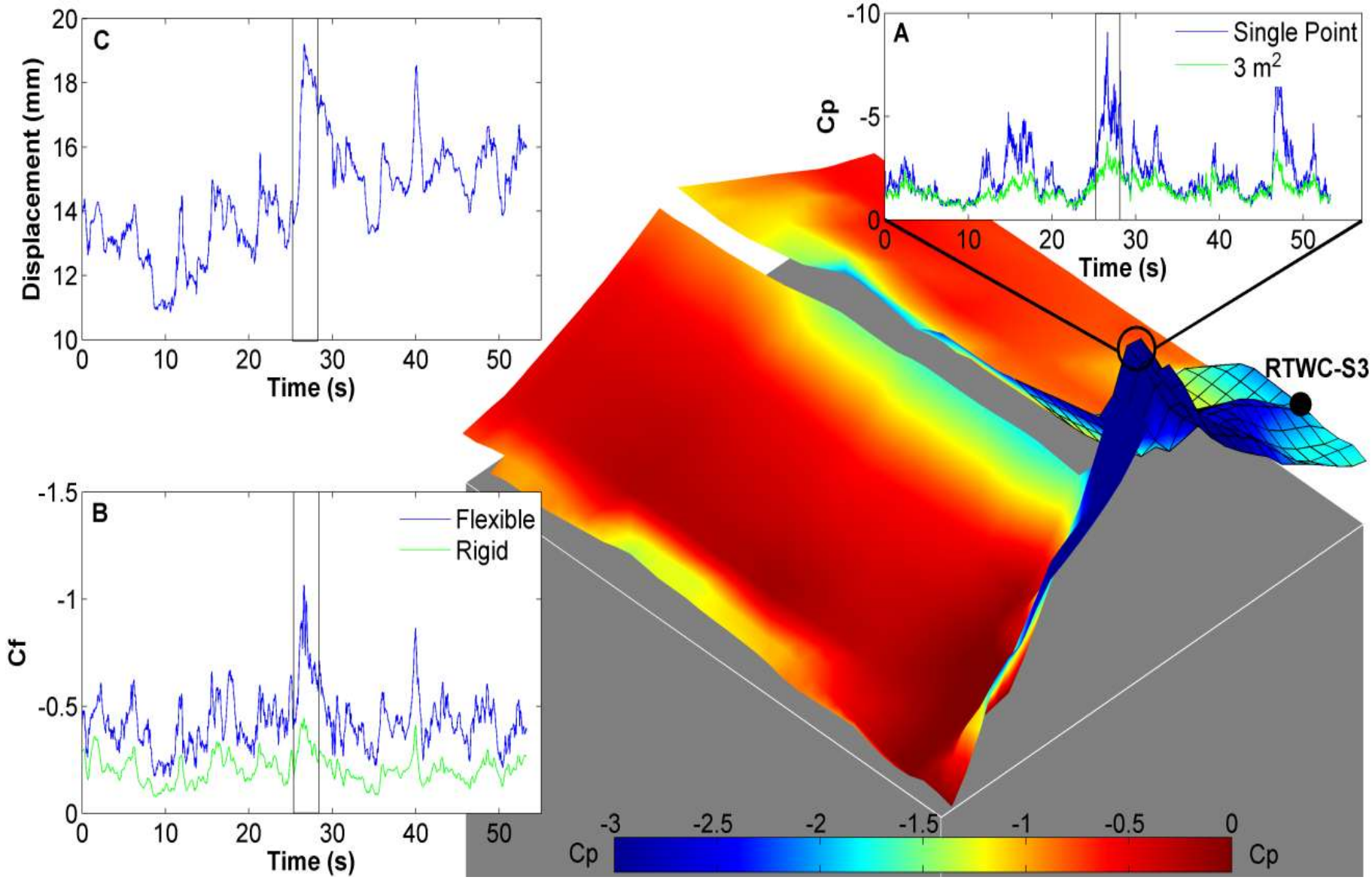


Full-scale tests at the “3 Little Pigs” project

THE '3 LITTLE PIGS' CONCEPT:


LOADING METHOD
Reaction frame
Pressure load actuators (PLAs)
Hoses connecting PLA with air boxes on roof of house
Ridge of 4:12 gable roof

LOAD SHARING BEHAVIOUR



Analysis of Roof Damage

Barrie Tornado, 1985

Wind Tunnel tests on houses

Wind tunnel study of houses

Roof Type	Roof Slope	Roof Dimension (L x W)	Building Eaves Height	Overhang Length	No. of Pressure Taps
Gable	5:12 and 6:12	11.34 m x 10.16 m (37.2' x 33.3')	3.6 m, 6.7 m, 9.1 m (11.7', 22.1', 30') (One-, Two-, Three-storey)	0.46 m (1.5')	230
	7:12, 9:12, and 12:12	11.28 m x 10.06 m (37' x 33')		0.51 m (1.67')	192
Hip	4:12	11.28 m x 10.06 m (37' x 33')		0.51 m (1.67')	592
	5:12 and 6:12	11.34 m x 10.16 m (37.2' x 33.3')		0.46 m (1.5')	242
	7:12, 9:12, and 12:12	11.28 m x 10.06 m (37' x 33')		0.51 m (1.67')	158

- Single, isolated houses and houses in 4 neighbourhood patterns
- Open and suburban terrain… 87 configurations in total

Effects of Building Parameters

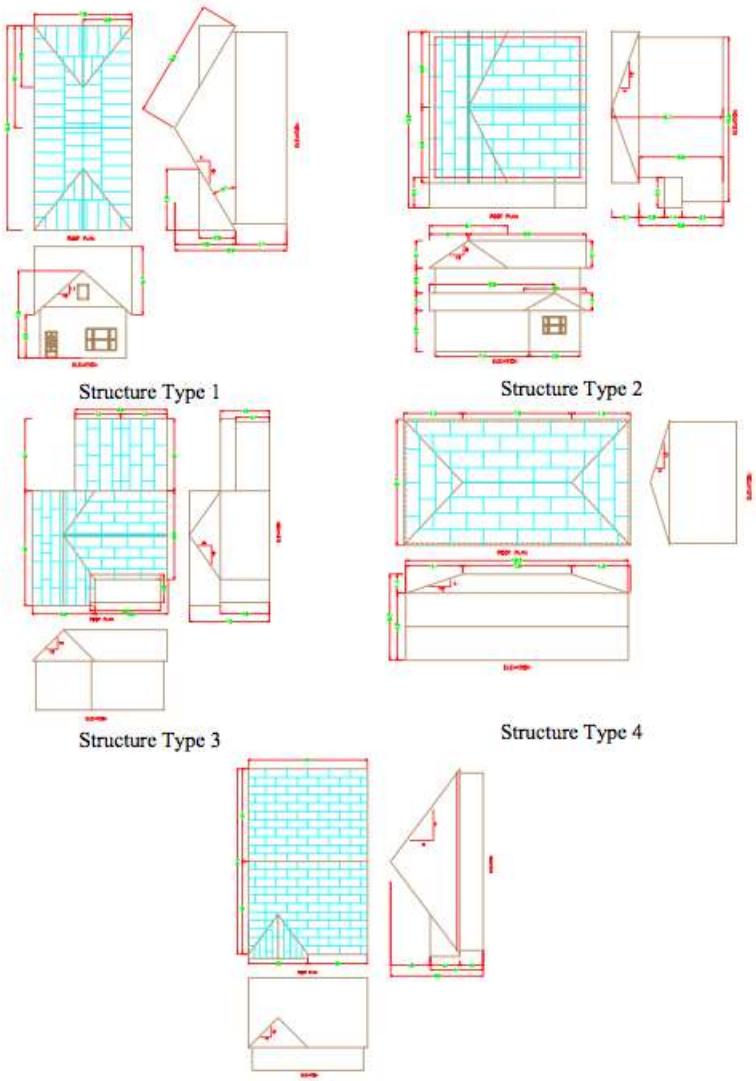


Fig. 2. Archetypes used in this study

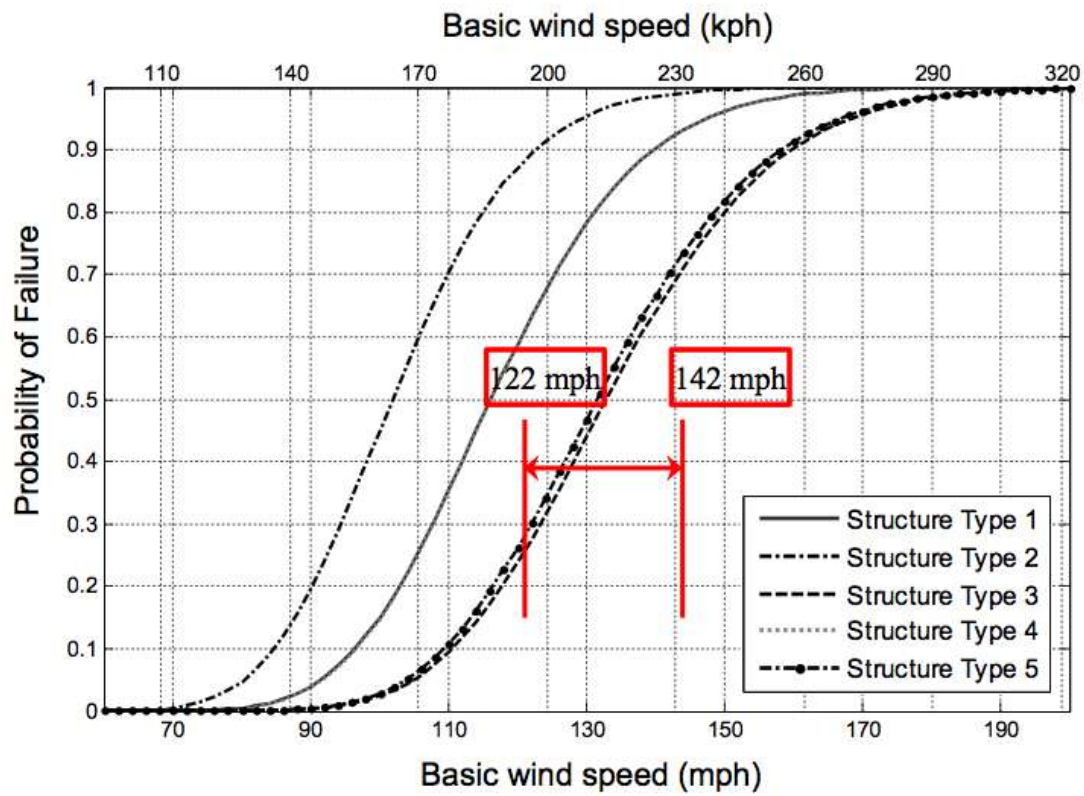


Fig. 12. H2.5 roof-to-wall connection for different structure types

Journal of Structural Engineering. Submitted September 18, 2012; accepted July 12, 2013; posted ahead of print July 15, 2013. doi:10.1061/(ASCE)ST.1943-541X.0000914

Quantitative Insight into Rational Tornado Design Wind Speeds for Residential Woodframe Structures Using a Fragility Approach

M. Omar Amini[1] and John W. van de Lindt[2], M. ASCE

Analysis of Roof Damage

Looking at the Barrie photo...

- Peak coefficient for hip roof is about 0.8. For a two storey gable it is about 1.2 (50% larger)
- Hip roofs have larger capacity due to connections on all 4 walls, compared to two walls for gable.
- These two factors lead to about a significant difference in failure wind speed.

- In Vaughan, we estimated that the gust speeds in the tornado were about 200 km/hr.

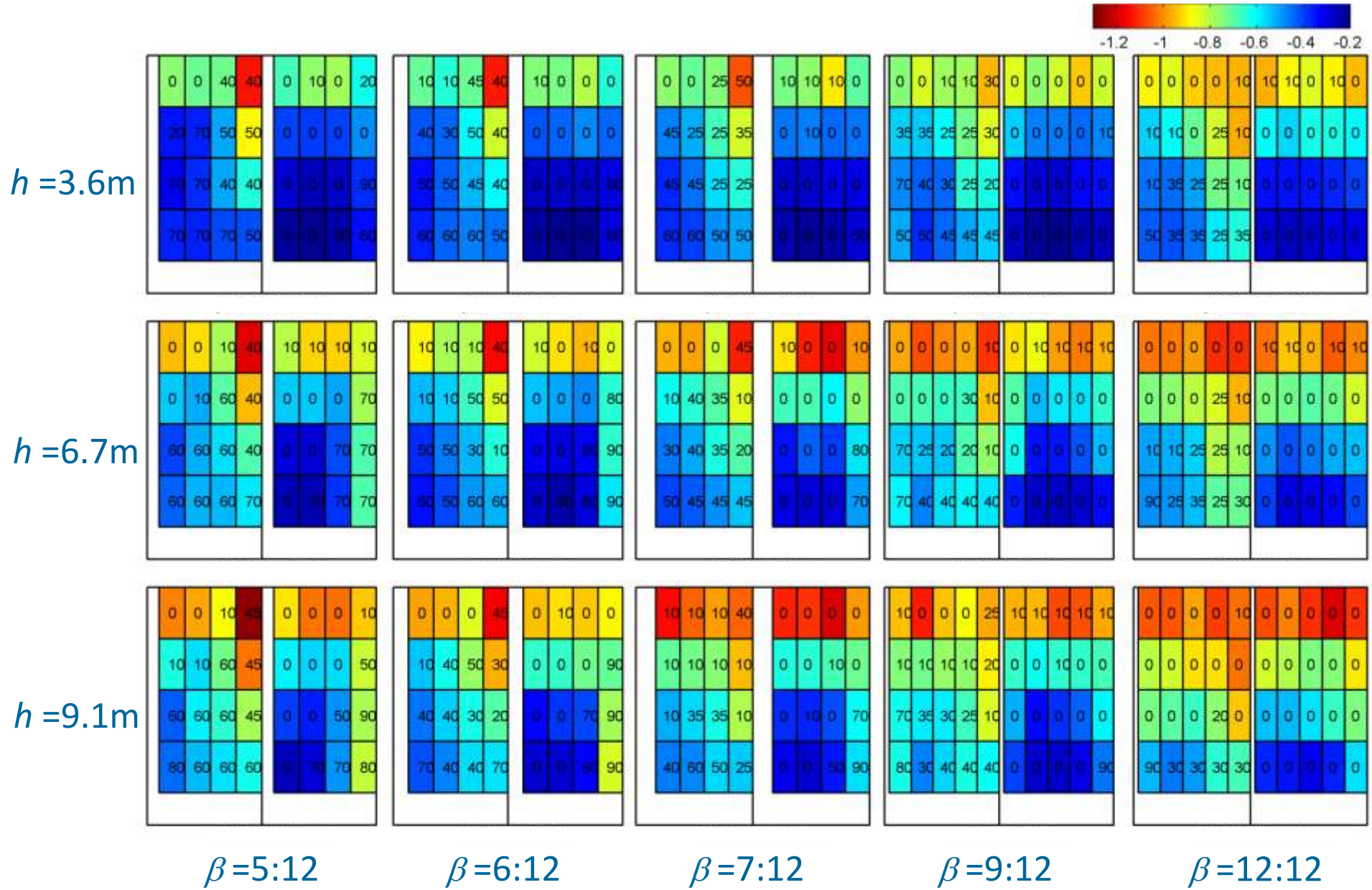
AND, if the houses had been fitted with hurricane straps, much of the structural damage would have been eliminated or reduced.

COST ESTIMATE for doing this? About $150/house

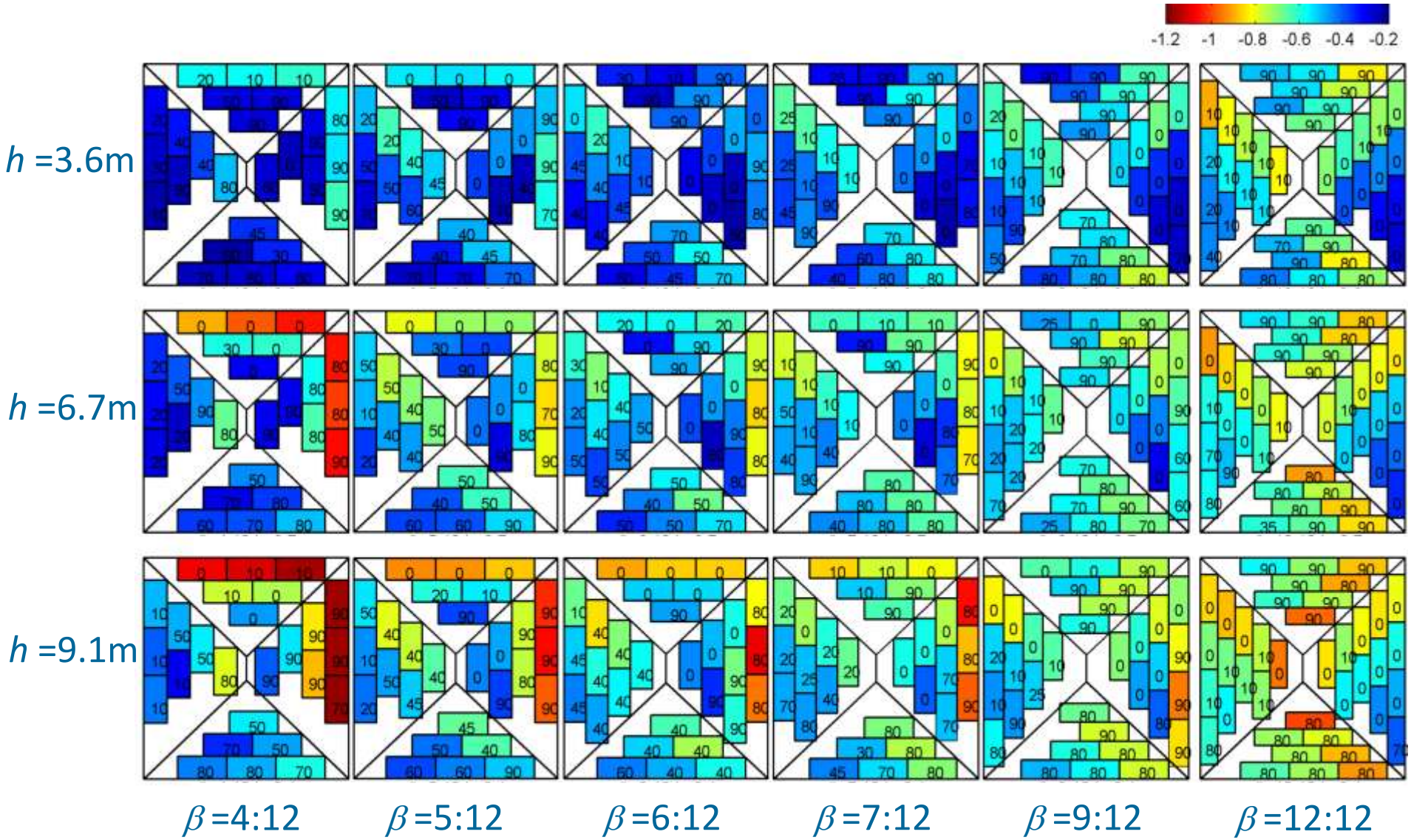
Roof Sheathing Panels

The details are important

Sheathing loads on gable roofs in suburban terrain (winds from north-east sector)



Sheathing loads on hip roofs in suburban terrain (winds from north-east sector)



FASTENERS

For roof sheathing

Size matters!!

A plywood sheet with 2 inch nails has about half the capacity of one with 2.5 inch nails.

That leads to a difference in failure-inducing wind speeds of about 40%, all else being equal!

Table 2. Fa

Fastener label; nailing pattern	Nominal length (mm)	Nominal shank diameter (mm)	Nominal crown (mm)	Nominal head area (mm²)	Mean capacity, R_{mean} (kPa)	CV of capacity, R_{CV}
6d common; 150/300	51	2.9	N/A	35.3	2.3*	0.19
6d spiral; 150/300	51	2.52	N/A	27.1	2.7*	0.14
16 gauge staples; 150/300	51	1.4 (16 gauge)	12.7	N/A	3.0*	0.13
Ring shank; 150/300	51	2.95	N/A	28.5	3.6*	0.16
8d spiral; 150/300	63	3.05	N/A	37.9	4.1*	0.10
16 gauge staples; 150/150	51	1.4 (16 gauge)	0.52	28.5	4.9†	0.10
HurriQuake§; 150/300	63	3.32	N/A	43.2	5.3†	0.11
8d spiral; 150/150	63	3.05	12.7	37.9	6.6‡	0.08
HurriQuake§; 150/150	63	3.32	N/A	43.2	8.5‡	0.08

Note: N/A, not applicable.
*Result from current test program.
†Result based on Henderson et al. (2013*a*).
‡Result estimated based on Henderson et al. (2013*a*) and Datin et al. (2011).
§HurriQuake is a trademark of Stanley Bostitch.

Roof Sheathing Panels

National Building Code Recommendations

Table 1. A portion

Element

Plywood, OSB or w
10 mm thick
Plywood, OSB or w
10 mm and up t

Note: N/A, not app
*Unless otherwise
†Staples shall not

1. Table 9.23.3.5.A of NBCC (2010) should be modified to apply only for HWP ≤ 0.4 kPa, not the current range of HWP < 0.8 kPa.
2. Table 9.23.3.5.B should apply for 0.4 kPa < HWP ≤ 0.8 kPa, with the number of fasteners adjusted to a spacing of 150 mm (o.c.) for both intermediate and edge supports.
3. For HWP > 0.8 kPa, engineering guidance should be obtained for design. Fortunately, only a handful of communities have such design wind speeds in Canada. There are fasteners with reasonable nailing patterns that are sufficient for sheathing panels up to HWP = 1.0 kPa.

m

300 mm (o.c.)
ts

s and Staples."

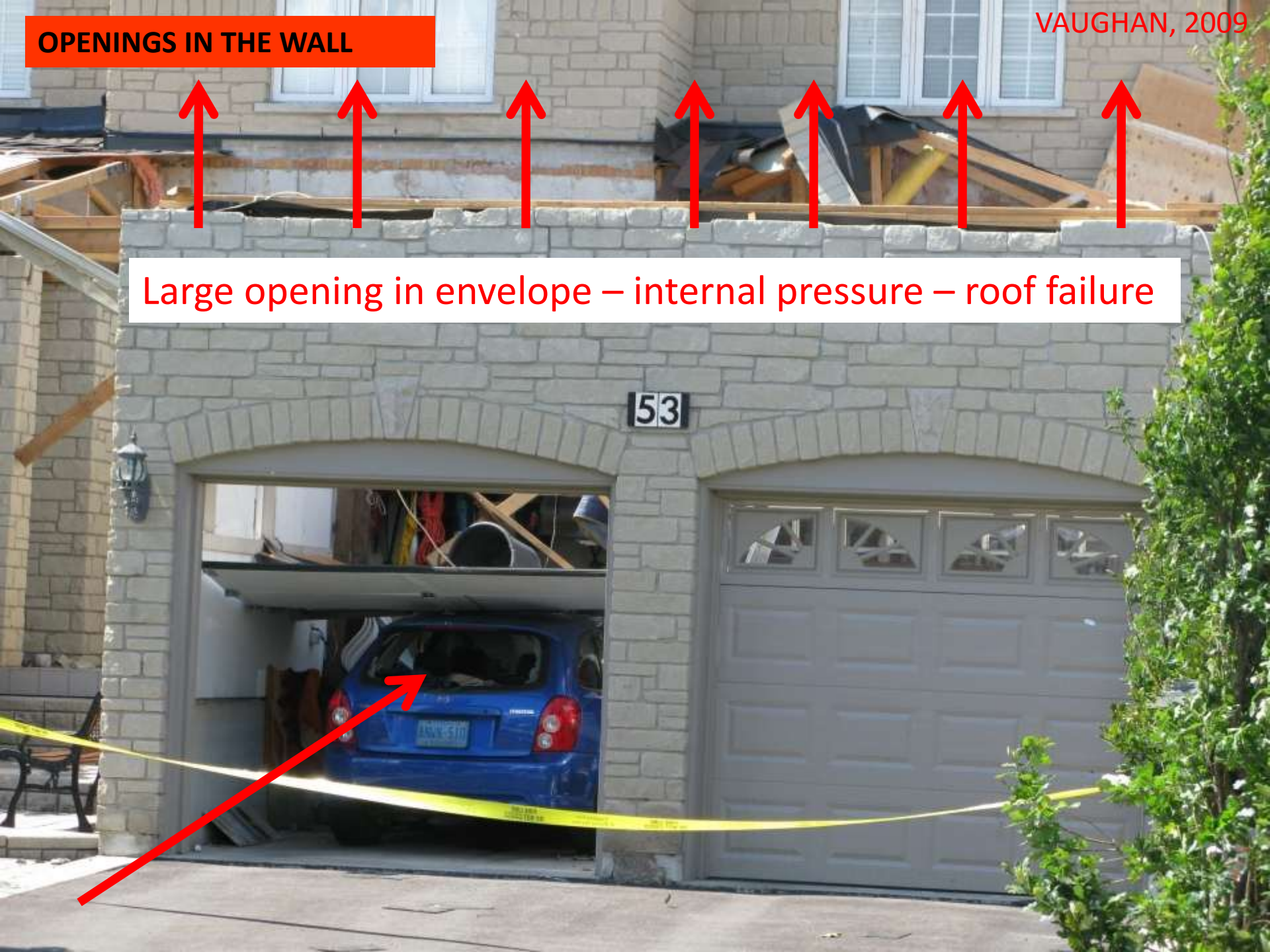
Our analysis shows this doesn't work… but the changes to make it work are simple.

Wind-borne debris

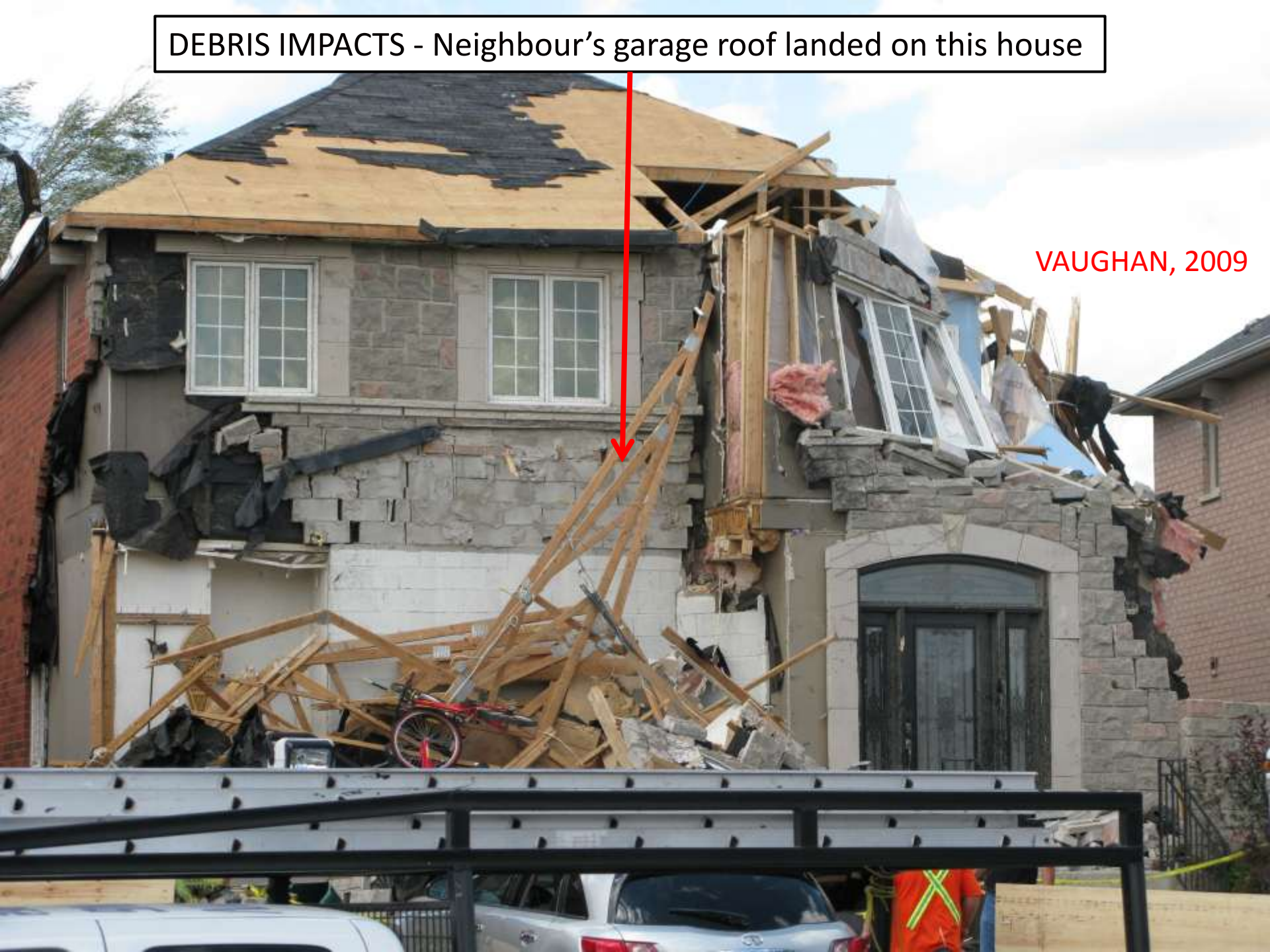
Goderich, ON, F3, August 2011

Wind-borne debris

Wind-borne debris


OPENINGS IN THE WALL
VAUGHAN, 2009
Large opening in envelope – internal pressure – roof failure
53

DEBRIS IMPACTS - Neighbour's garage roof landed on this house



Wind-Borne Debris Impacts

Wind-Borne Debris Impacts

Wind-Borne Debris Impacts

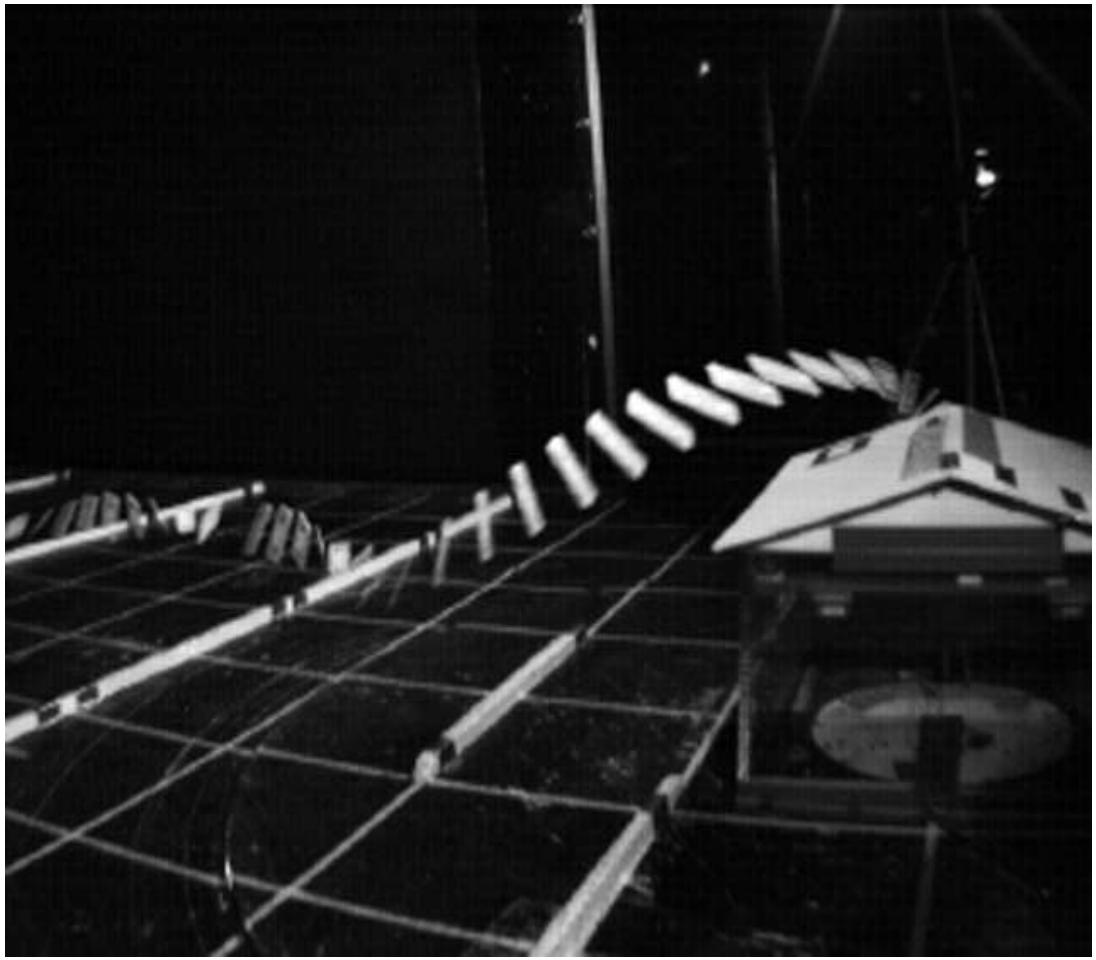
Roof tiles – transport distances and speeds

Photo courtesy of Tim Reinhold

Trajectory Results for Roof Sheathing

Initial Overturning Failure

Translational Movement

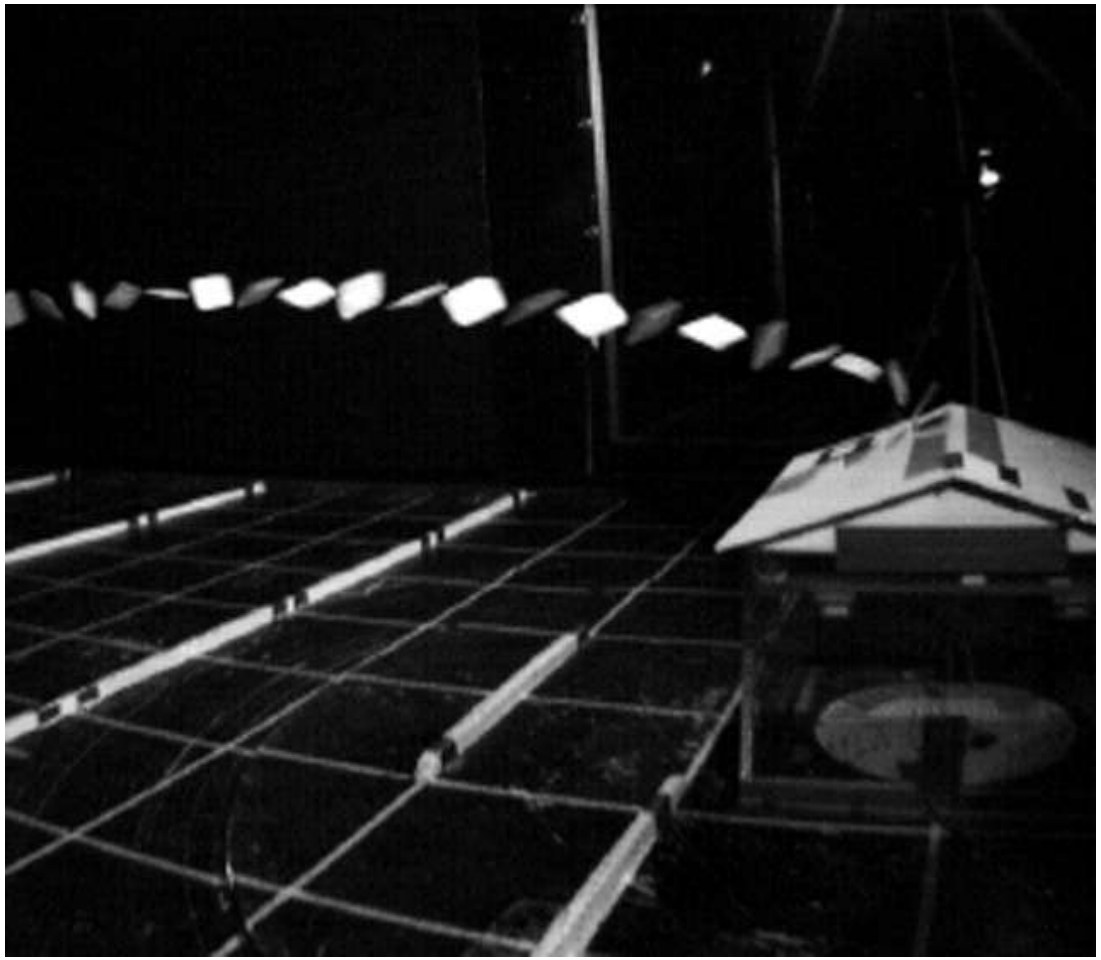


Trajectory Results for Roof Sheathing

Initial Overturning Failure

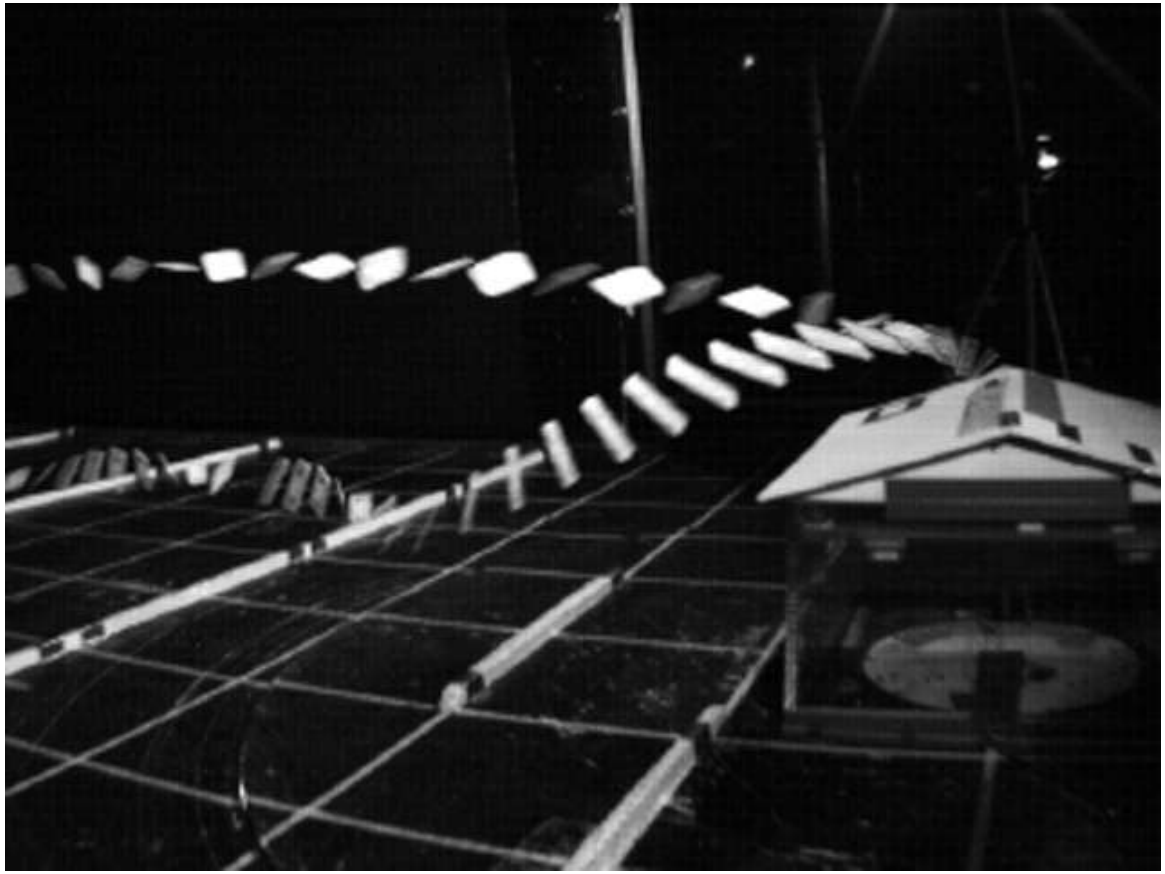
Auto-rotational Movement

Upward Lift

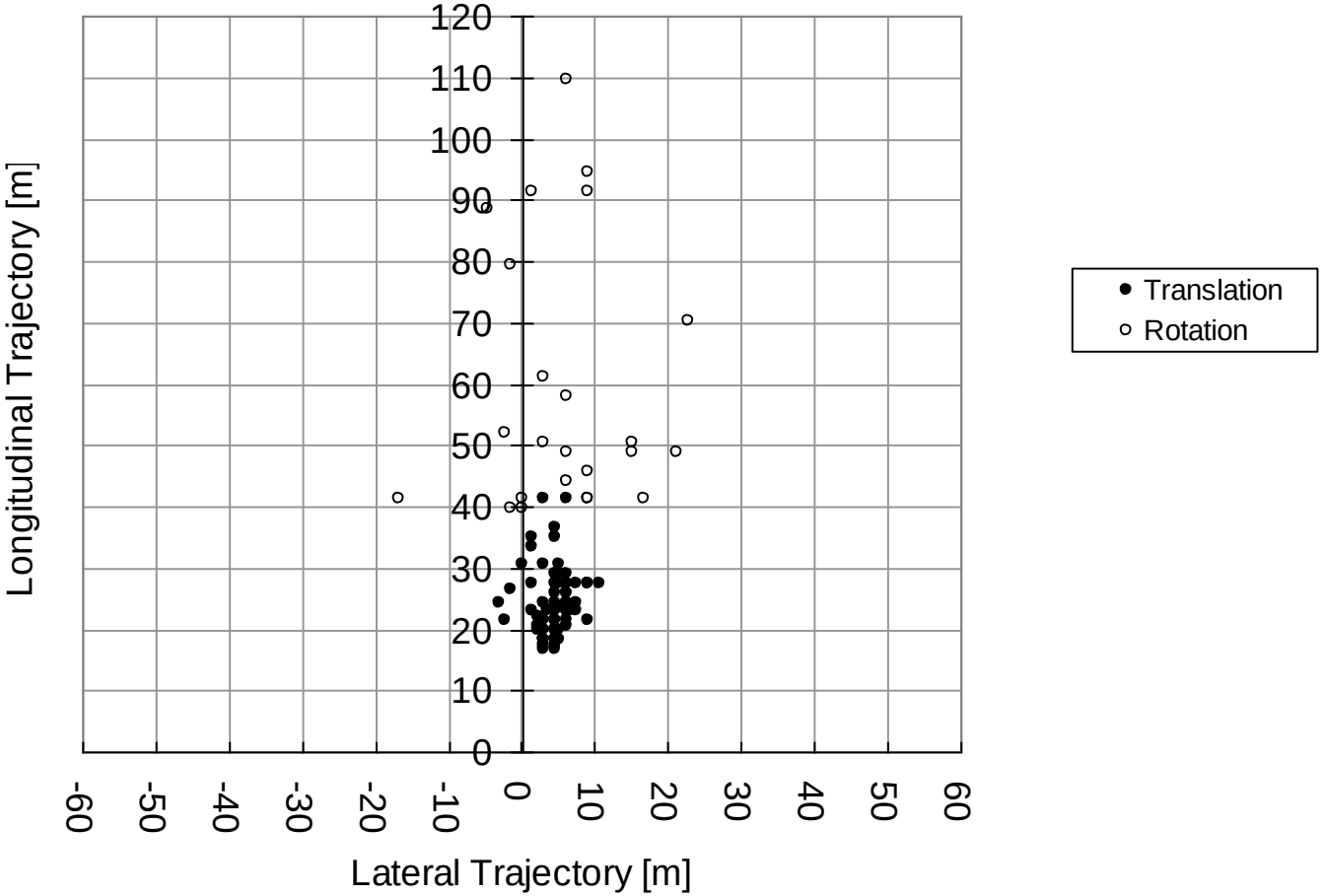


Trajectory Results for Roof Sheathing

Distinctly different flight patterns are observed, even though these are originating from the same (nominal) initial condition.



Flight Distances for Roof Sheathing Panels



High speed images of **shingle impact** on glass

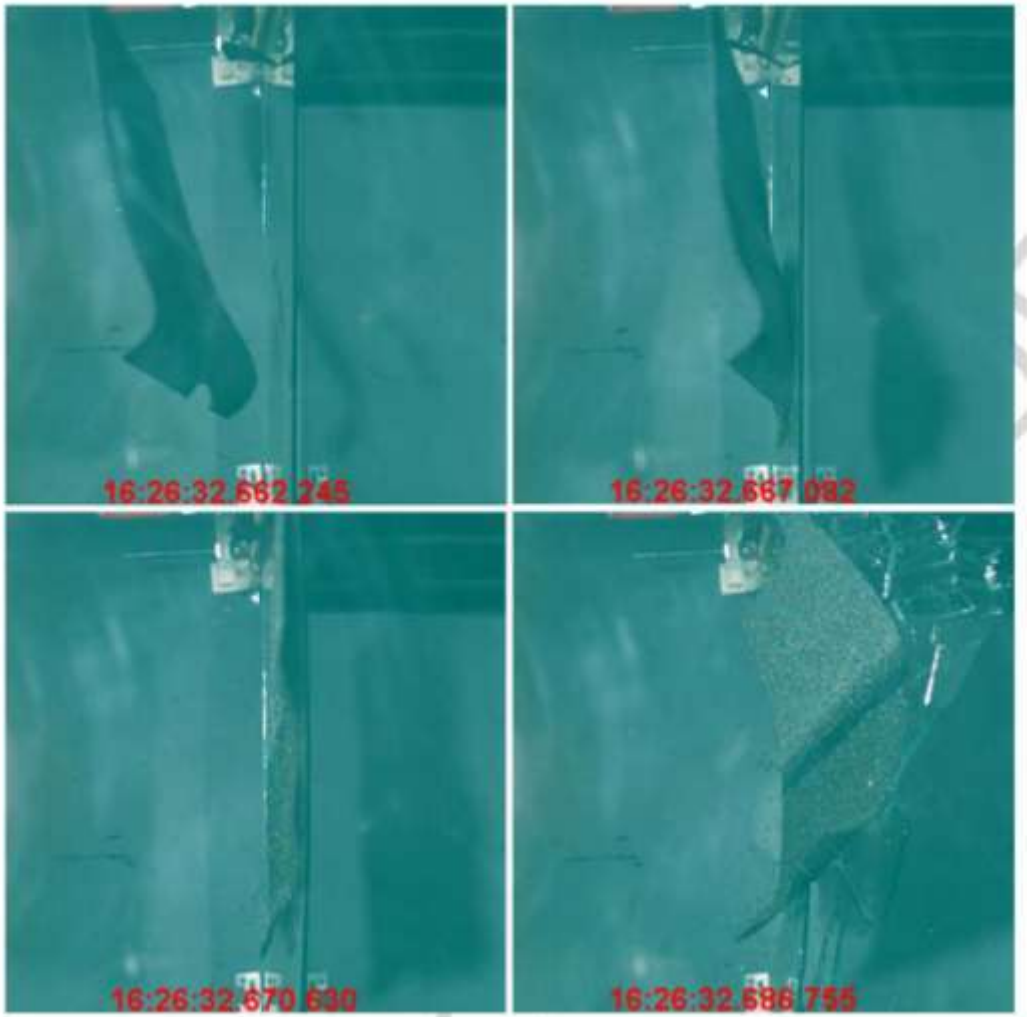
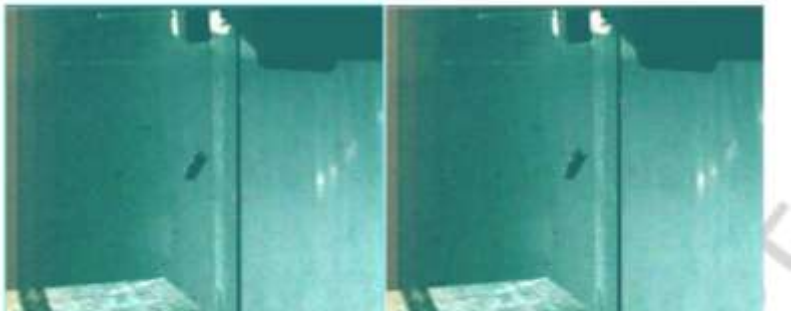


Fig. 2. High speed imagery of a tumbling shingle impact (Phase 1 testing).

Courtesy of F.Masters & K.Gurley, Univ. Florida

High speed images of **shingle impact** on glass



We have found that the flight speed of shingles released from a residential rooftop of common slope can range from 50% to 120% of the roof height gust speed

Winds strong enough to remove shingles from a rooftop are highly likely to have sufficient momentum to break a typical residential double-strength window pane!

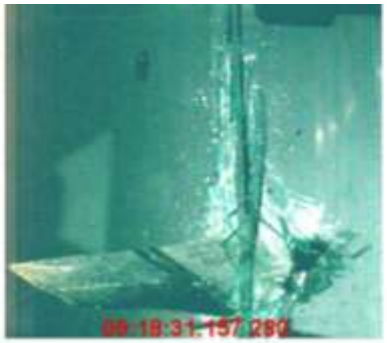


Fig. 3. High speed imagery of a spinning shingle impact (Phase 1 testing).

Courtesy of F.Masters & K.Gurley, Univ. Florida

SUMMARY

We need to keep the roof structure intact in order to reduce effects of wind-borne debris impacts….

We also need to keep the roof structure intact for life safety and for mitigation of economic losses in wind storms.

Much of this type of damage can be mitigated, for approximately $200/house…

we would be left with shingles and siding loss, but the costs associated with these are much less.

…perhaps not the best solution, but maybe cheaper

For Want of a Nail

For want of a nail the shoe was lost.
For want of a shoe the horse was lost.
For want of a horse the rider was lost.
For want of a rider the message was lost.
For want of a message the battle was lost.
For want of a battle the kingdom was lost.
And all for the want of a horseshoe nail.

Questions?

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