Cyclone Larry, Australia, 2006

Full-Scale Testing at the Insurance Research Lab for Better Homes

Gregory Kopp

Insurance Research Lab for Better Homes
Faculty of Engineering, University of Western Ontario

“We know enough about the wind loads on low buildings now, so that disastrous failures (such as seen during Hurricane Andrew) to storms other than severe tornadoes, are much more likely to be due to faults in codes, or construction and inspection practices, than due to lack of basic wind engineering knowledge.”

- *D. Surry, 1999, at 10th ICWE*

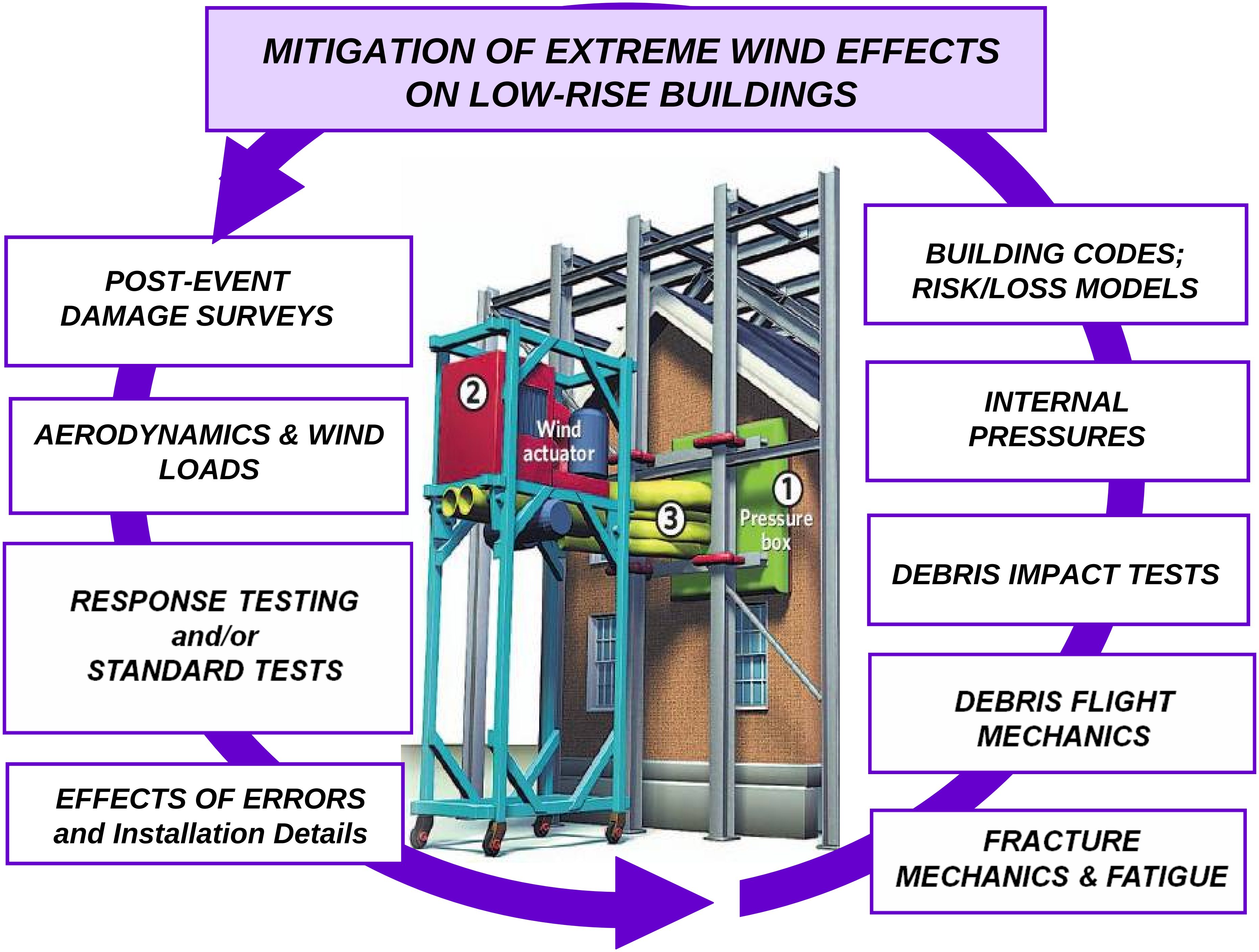
The recent Gulf Coast and Australian hurricanes have indicated there are still significant problems primarily for these reasons.

Vision Statement

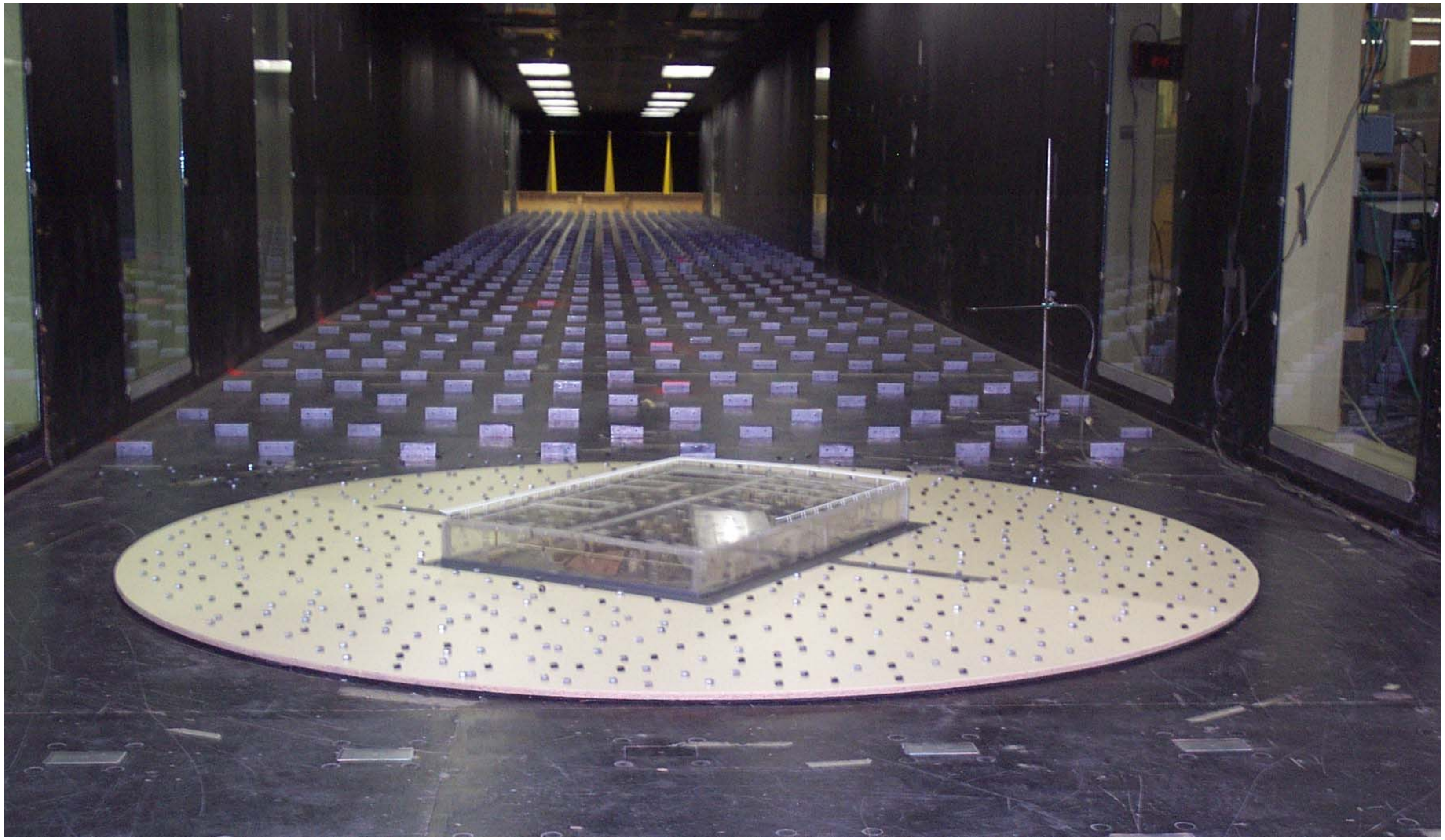
To find optimal solutions which mitigate damage to homes, and other light frame structures, under extreme environmental conditions; conditions such as wind, wind-driven rain, snow, and the various factors that support mould growth.

Detailed Project Objectives

1. Develop new testing methods which allow the examination of structural and component responses under realistic wind loads.
2. Calibrate simplified industry standard tests against the “reality” of dynamic wind loads and current/future building codes.
3. Find prescriptive design solutions for wood-frame structures (houses) and building components, incorporating effects of errors.
4. Improve the design and installation of building materials in partnership with builders and manufacturers.
5. Improve computational and simplified experimental methodologies so other cases can be examined
6. Educate the public on safety issues in partnership with governmental agencies and insurance industry
7. Perhaps… develop/test new building systems for houses which perform the key aspects of housing systems (environmental control and structural reliability) in a more unified manner


MITIGATION OF EXTREME WIND EFFECTS ON LOW-RISE BUILDINGS
POST-EVENT DAMAGE SURVEYS
AERODYNAMICS & WIND LOADS
RESPONSE TESTING and/or STANDARD TESTS
EFFECTS OF ERRORS and Installation Details
BUILDING CODES; RISK/LOSS MODELS
INTERNAL PRESSURES
DEBRIS IMPACT TESTS
DEBRIS FLIGHT MECHANICS
FRACTURE MECHANICS & FATIGUE
2
Wind actuator
3
1
Pressure box

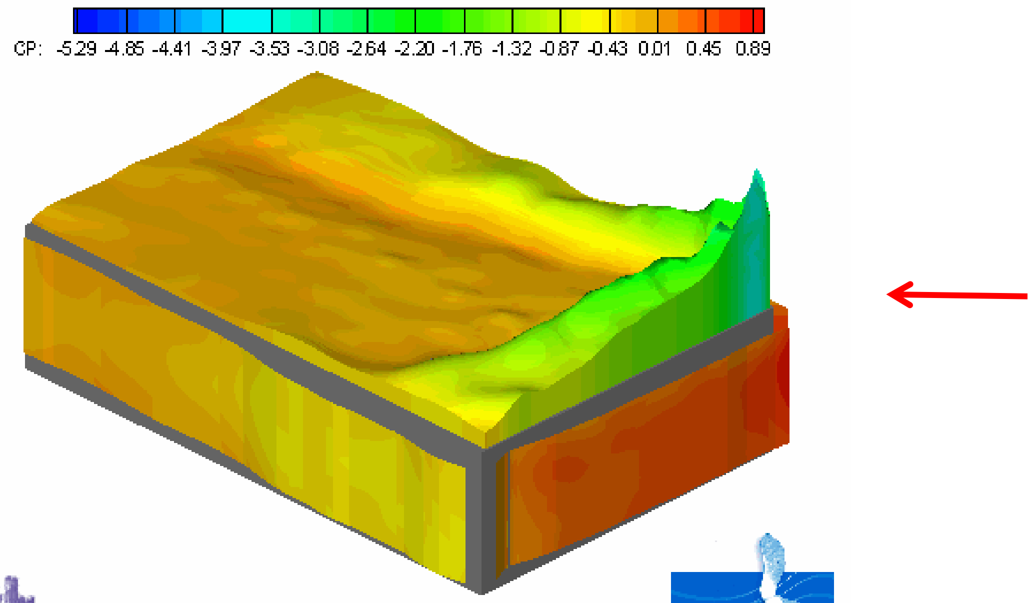
Basic wind tunnel testing



Wind Loading on Low-Rise Buildings

Smoke visualization of flow on roof of building

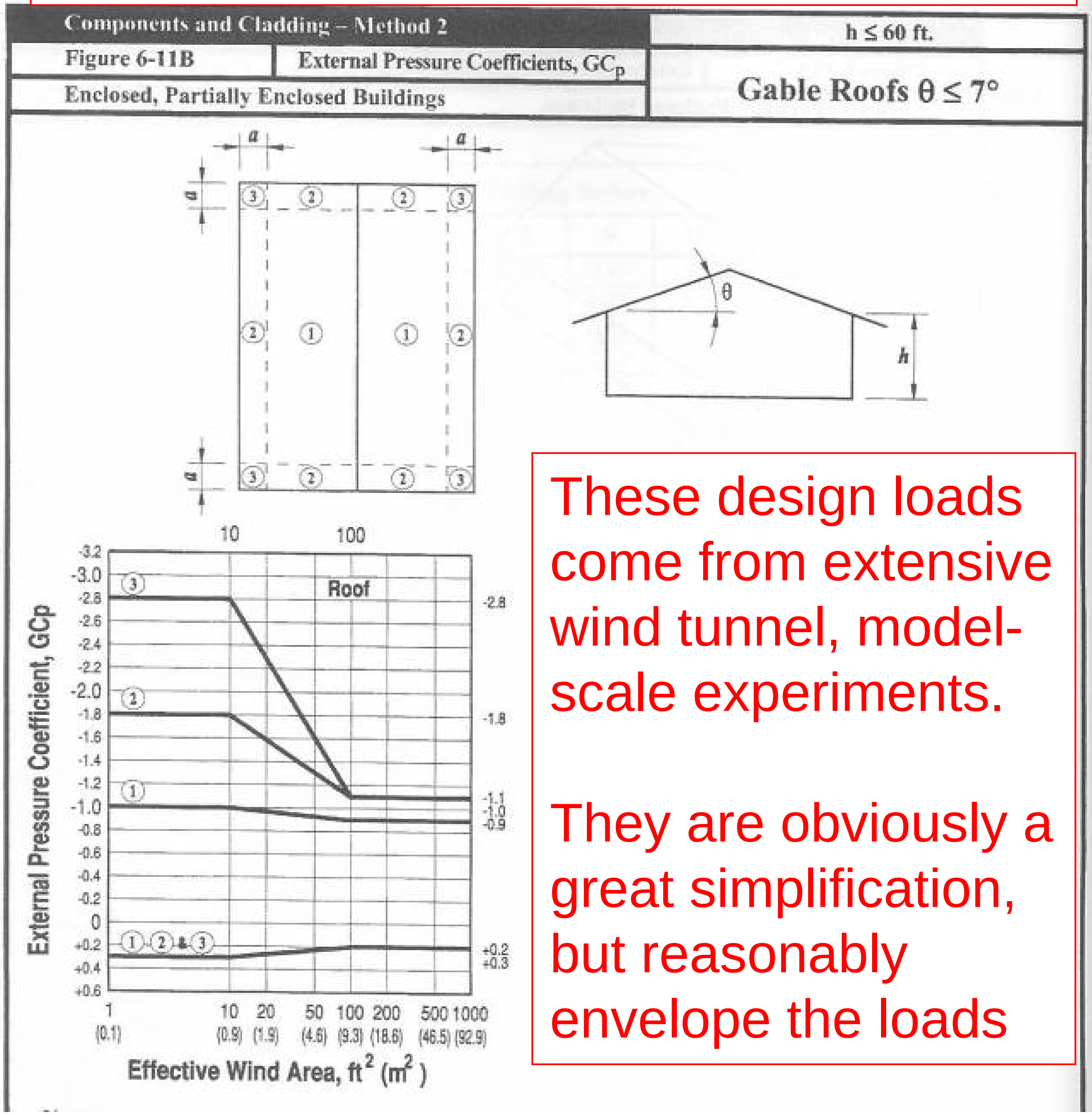
Wind Loading on Low-Rise Buildings



Western

The Boundary Layer Wind Tunnel Laboratory

Building Codes (ASCE 7-05)

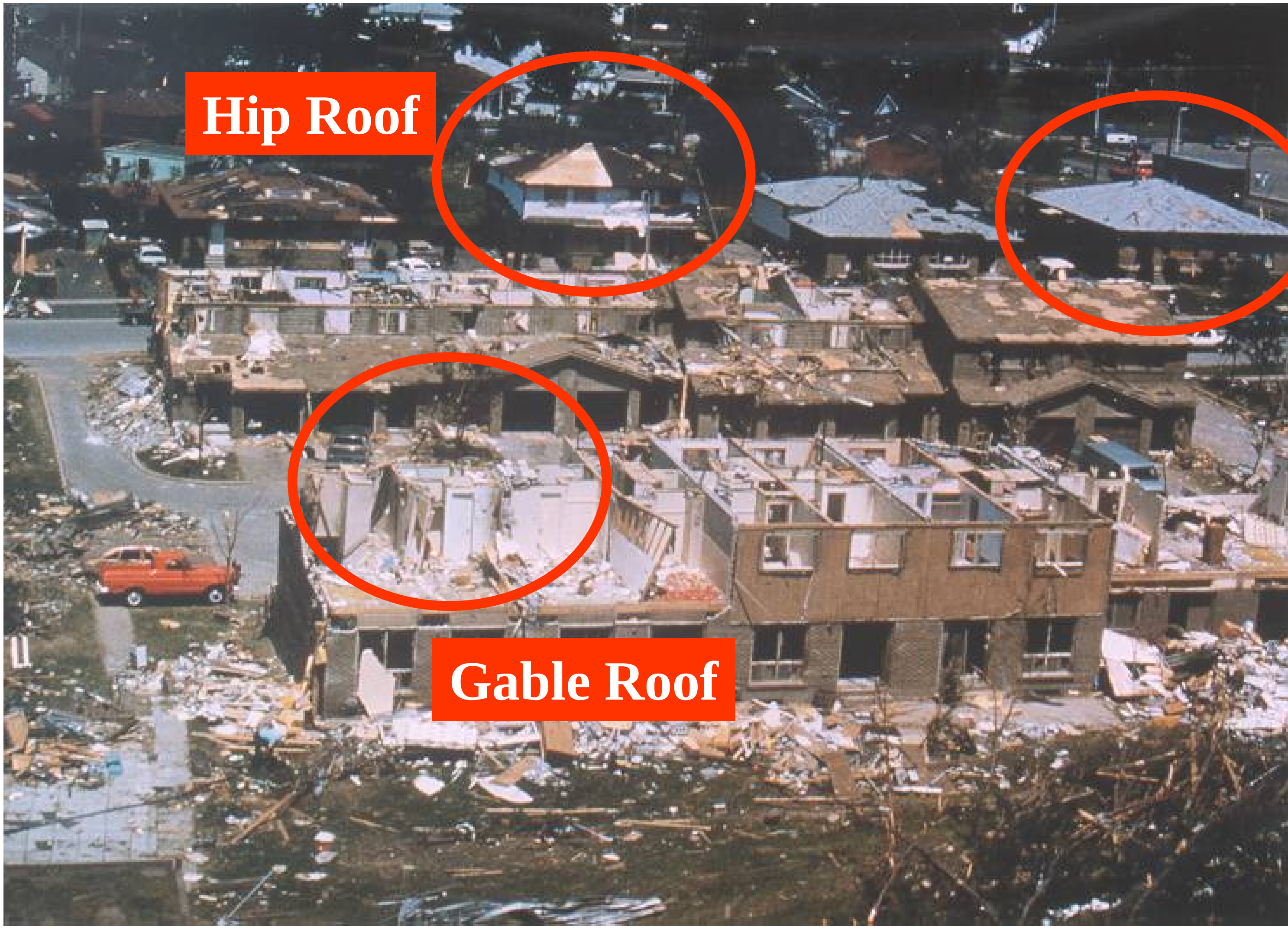


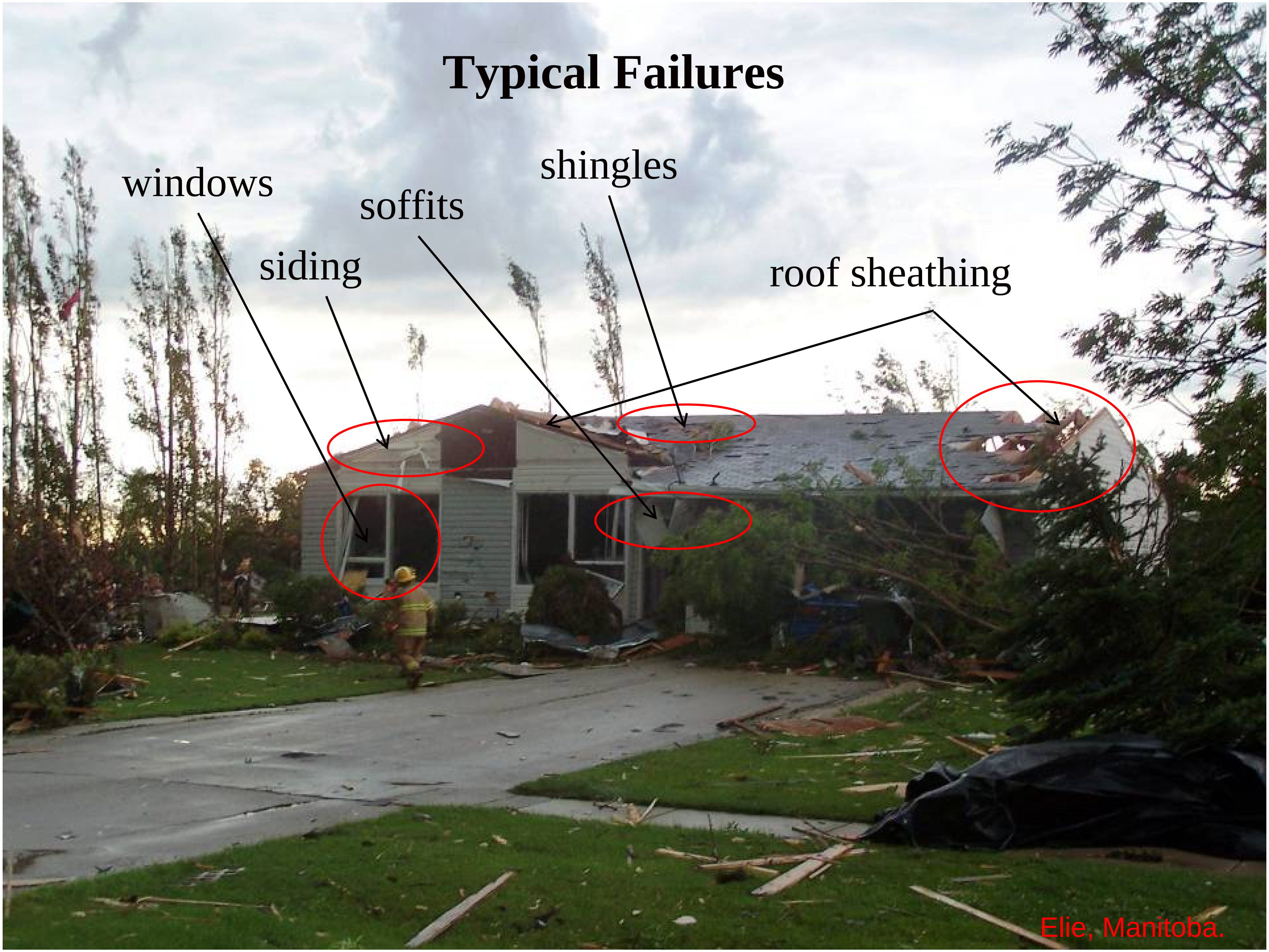
These design loads come from extensive wind tunnel, model-scale experiments.

They are obviously a great simplification, but reasonably envelope the loads

Building shape plays a significant role on the loading, as does the structural system

Barrie Tornado, 1985



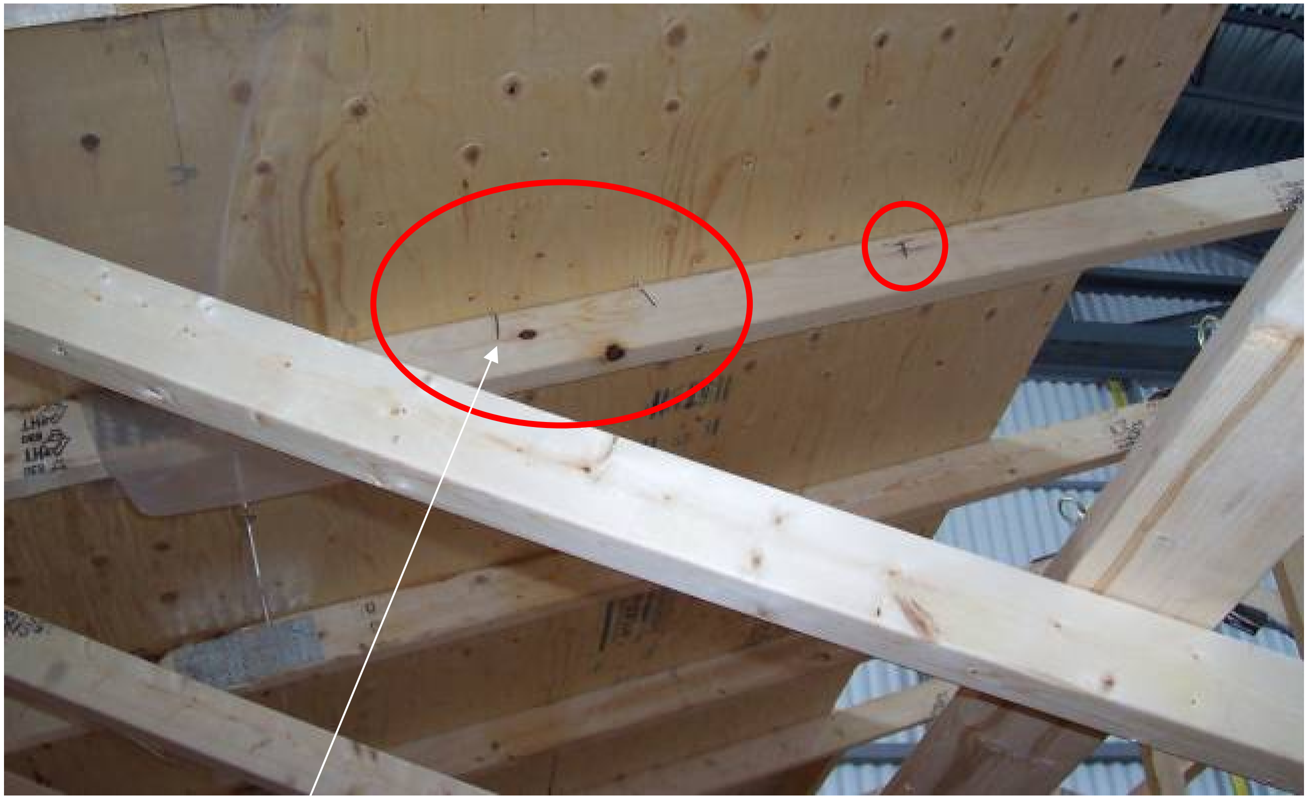

Typical Failures
windows
soffits
shingles
siding
roof sheathing
Elie, Manitoba.

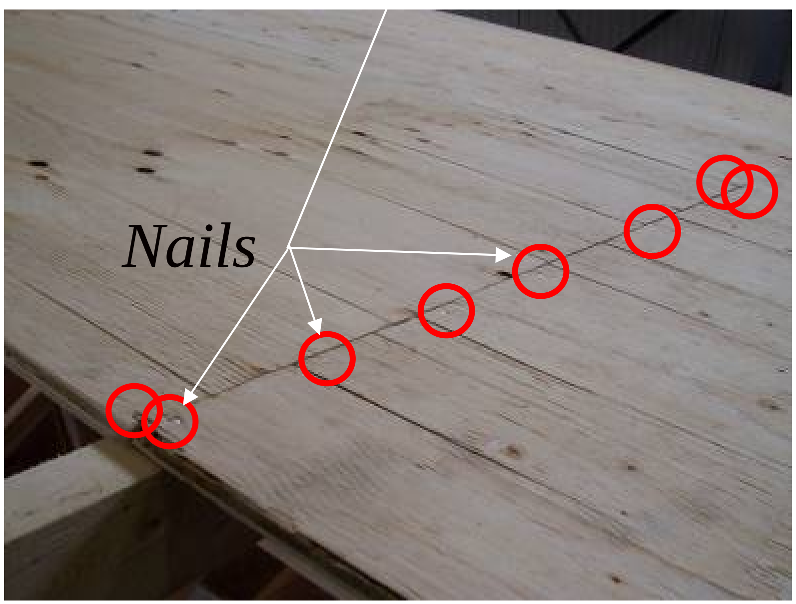

car
'missing' house

same car
MISSING hold-downs

Missing foundation connections are a life safety issue in tornadoes

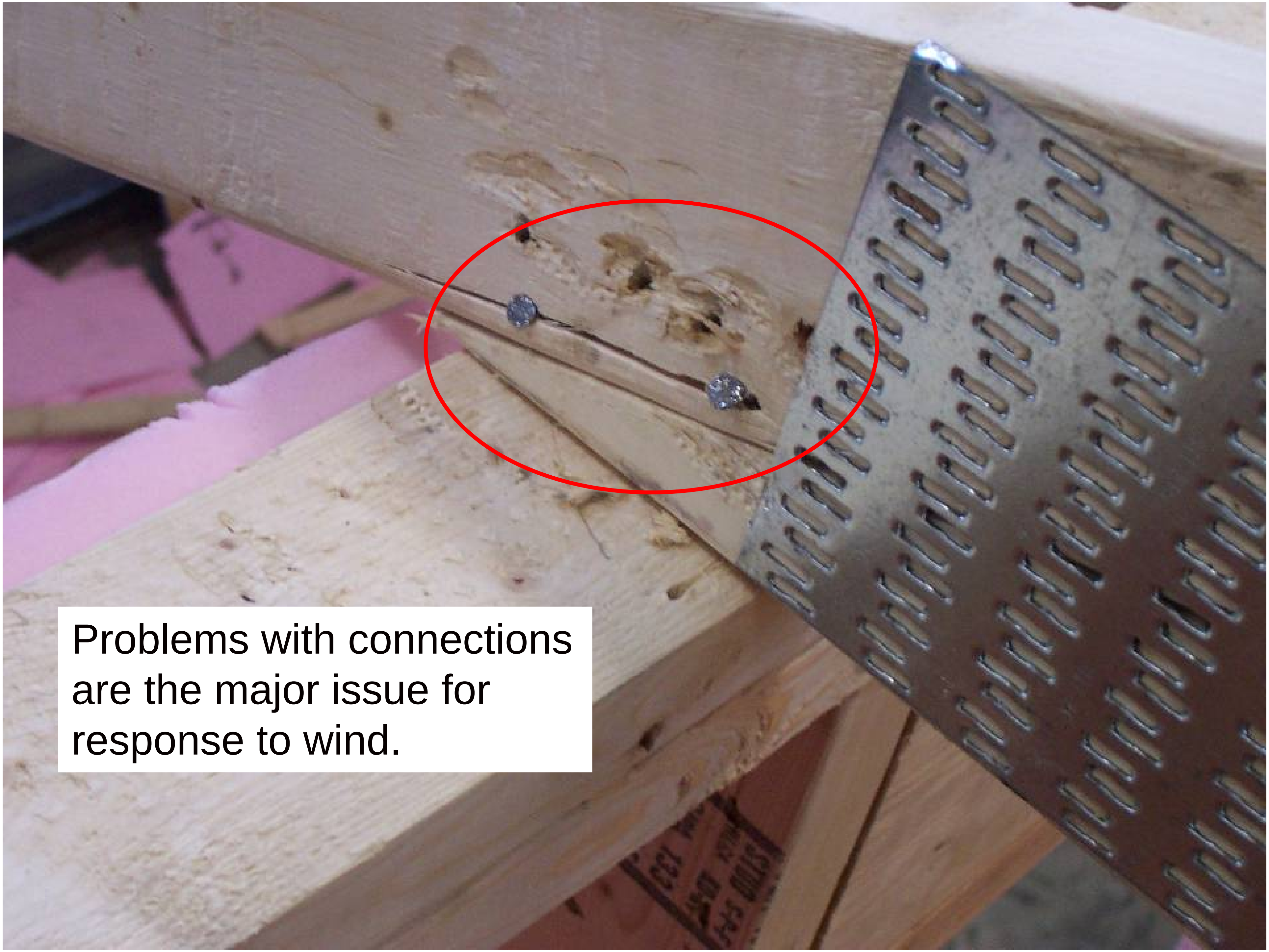
Details such as this are important to observe and identify in damage surveys so that a proper engineering analysis can be performed.





Variability in performance arises because of errors and variability in materials.

(Photos of 3LP test house)



Problems with connections are the major issue for response to wind.

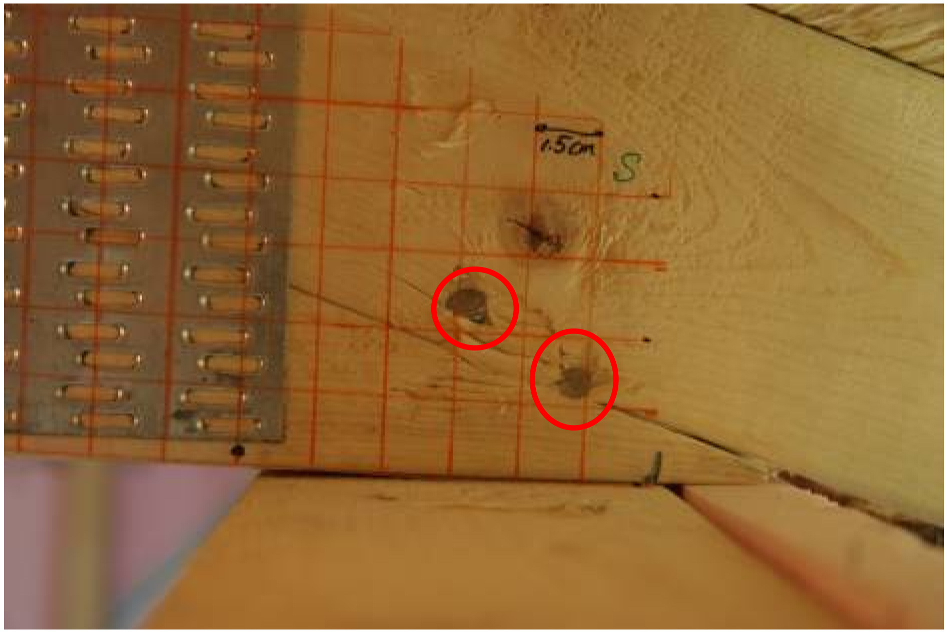
Hurricane Gustav (2 weeks ago)

We found one house in Houma, LA with a roof failure (city of 100,000 people). The cause of the damage was missing toenails.

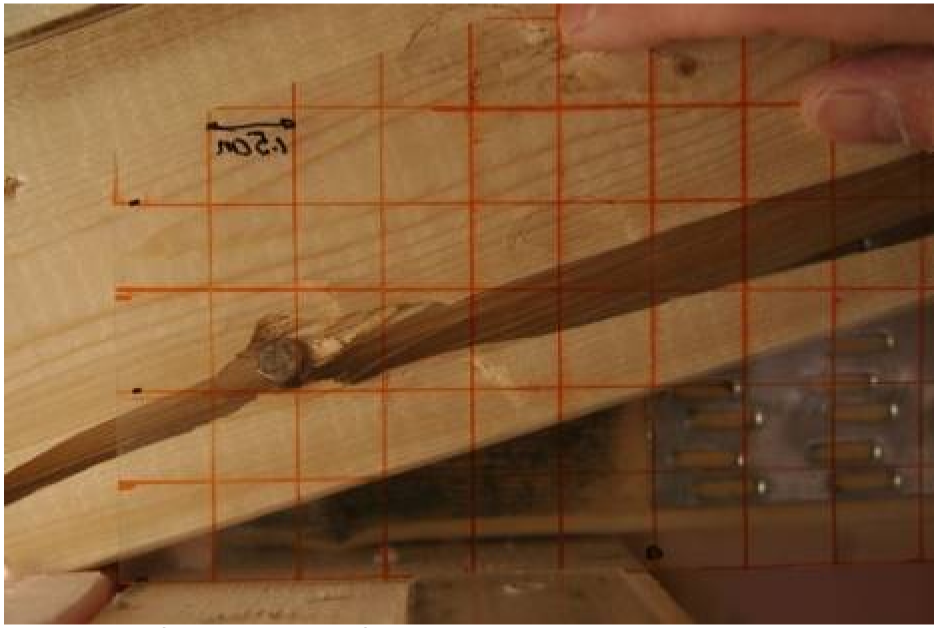
The roof flew off the left house and landed on the roof of the right house, penetrating the sheathing.

Roof-to-Wall Connections

- **Estimates of the hold down capacity of toe-nail connections on the test house vary from 30lbf to 160lbf (based on past literature)**
- **Every connection (roof sheathing and roof-to-wall toe-nails) in the house has been recorded to aid in the interpretation of the experimental data and to aid computational modeling.**
- **These data will be used for the development of probabilistic failure (risk) models**



A typical toe-nail roof to wall connection in the test house



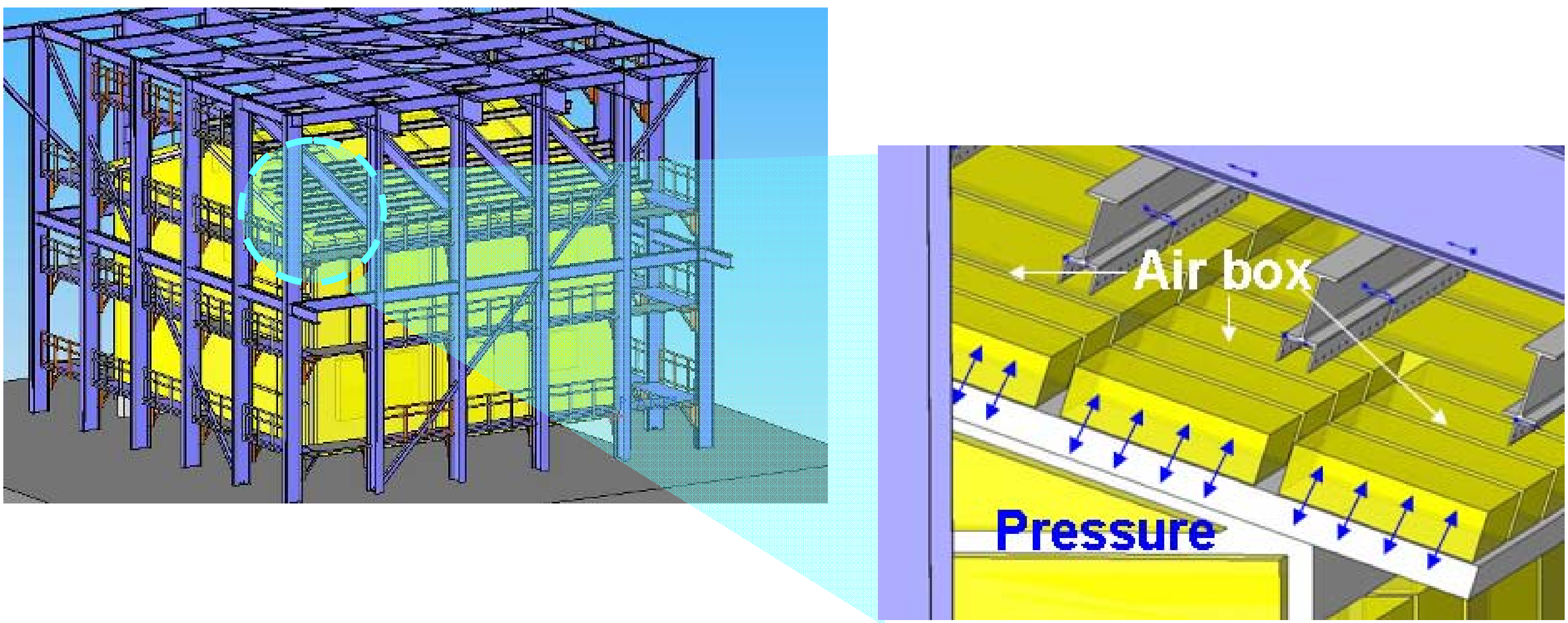
Example of a toe-nail roof to wall connection in the house where the nail has split the wood and offers very little hold down force.

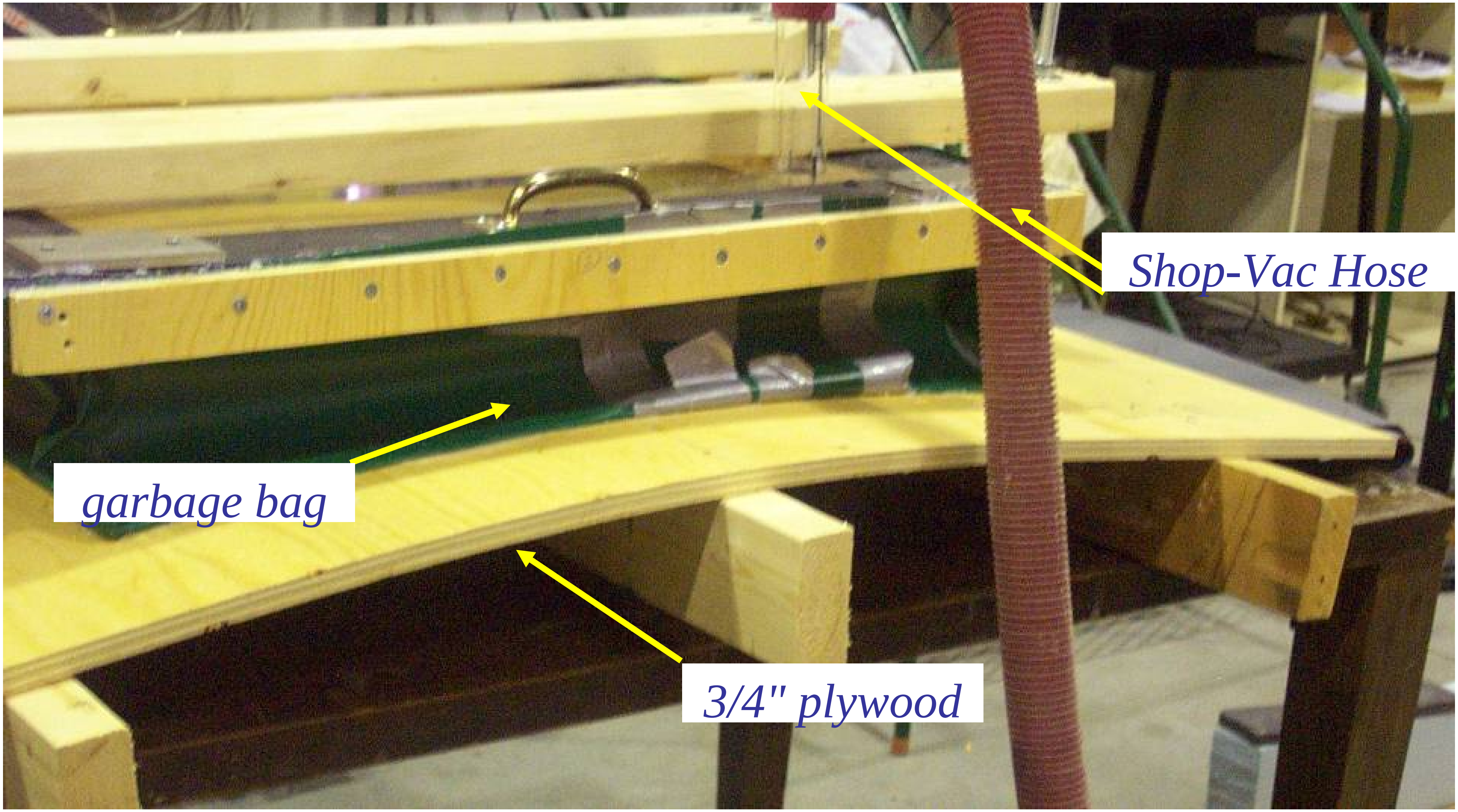
Full-scale tests on a fully-instrumented 2-storey house

August 2008

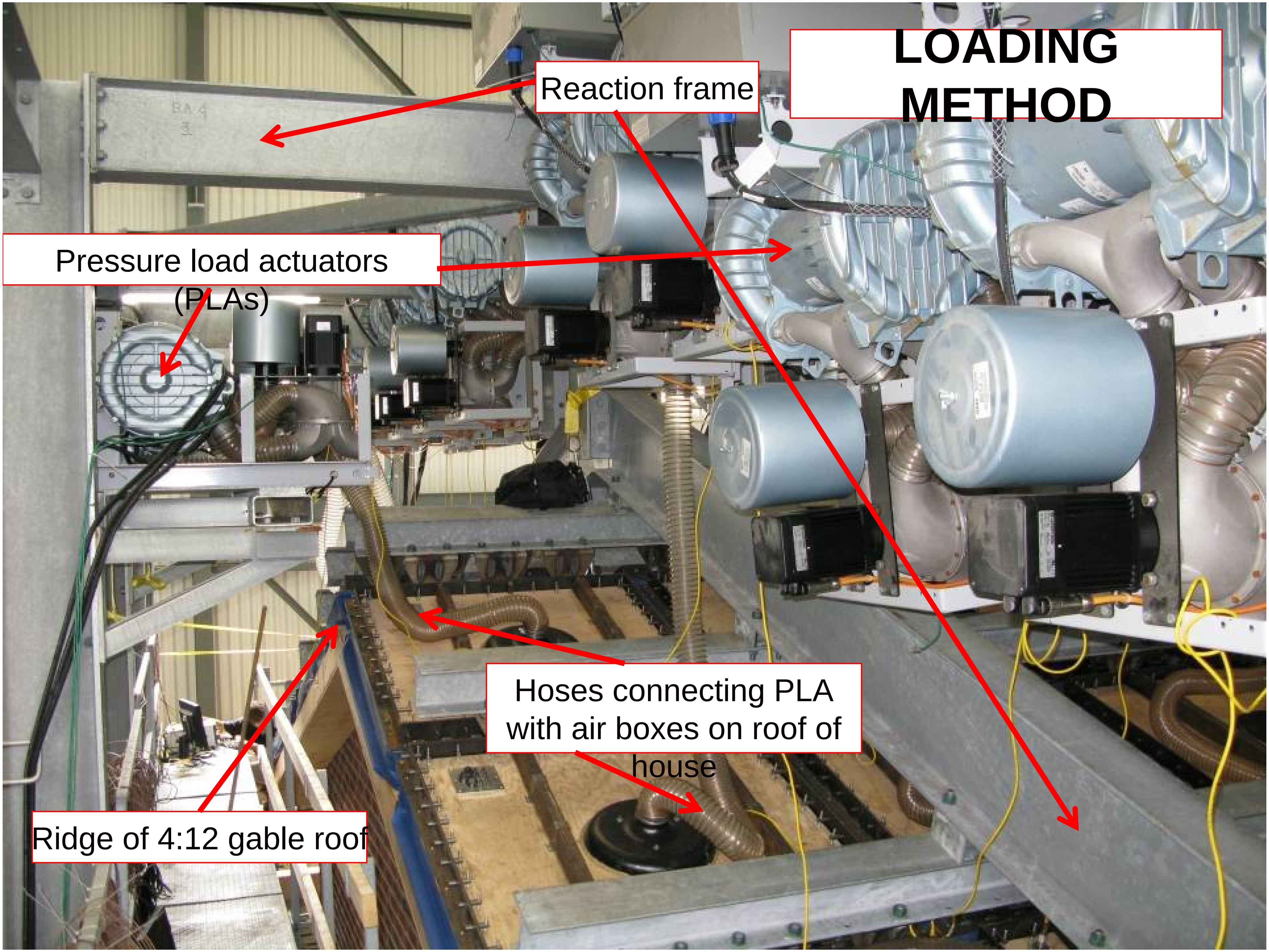
LOADING METHOD

Testing required surrounding the house with ‘airboxes’ and use of the novel ‘pressure loading actuators’ developed for the Project





The loading concept is simple;
we replicate the pressures that the wind induces.
Fans are used, NOT TO BLOW WIND, but more like a vacuum cleaner!


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

Specifications for the Pressure Loading Actuators

We want to apply up to a Cat. 5 hurricane

- Applied pressures over different areas: 2ft x 2ft, 4ft x 4ft, and 8ft x 8ft (nominal):

  2ft x 2ft box pressure range of +100/-400 psf

  4ft x 4ft box pressure range of +100/-300 psf

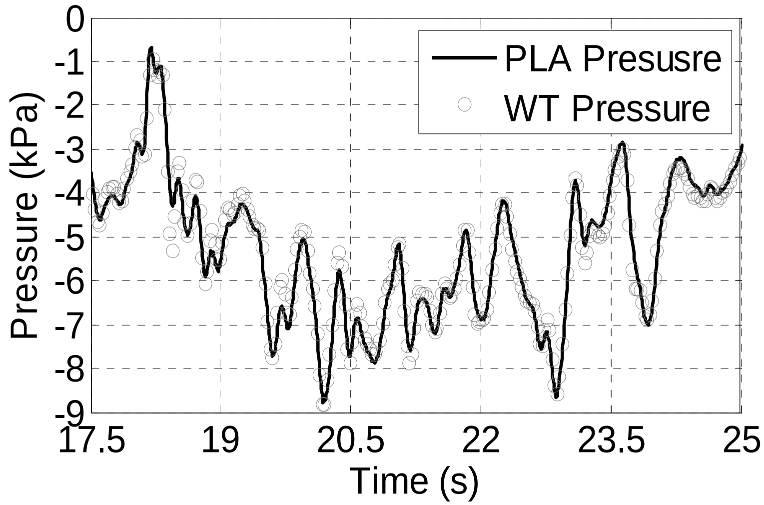
  8ft x 8ft box pressure range of +80/-200 psf,

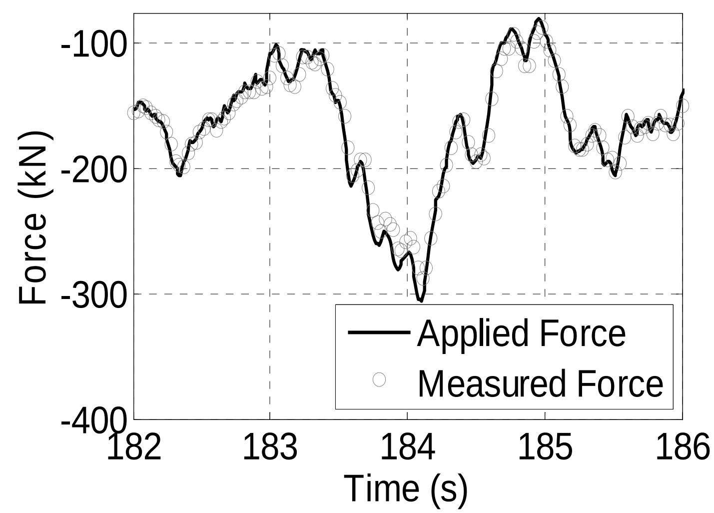
- Frequency response in the range of 4 – 7 Hz

- Large leakage flow rates to allow testing of porous materials such as bricks, or materials with cracks

- Turn down ratio on pressures is 1/10

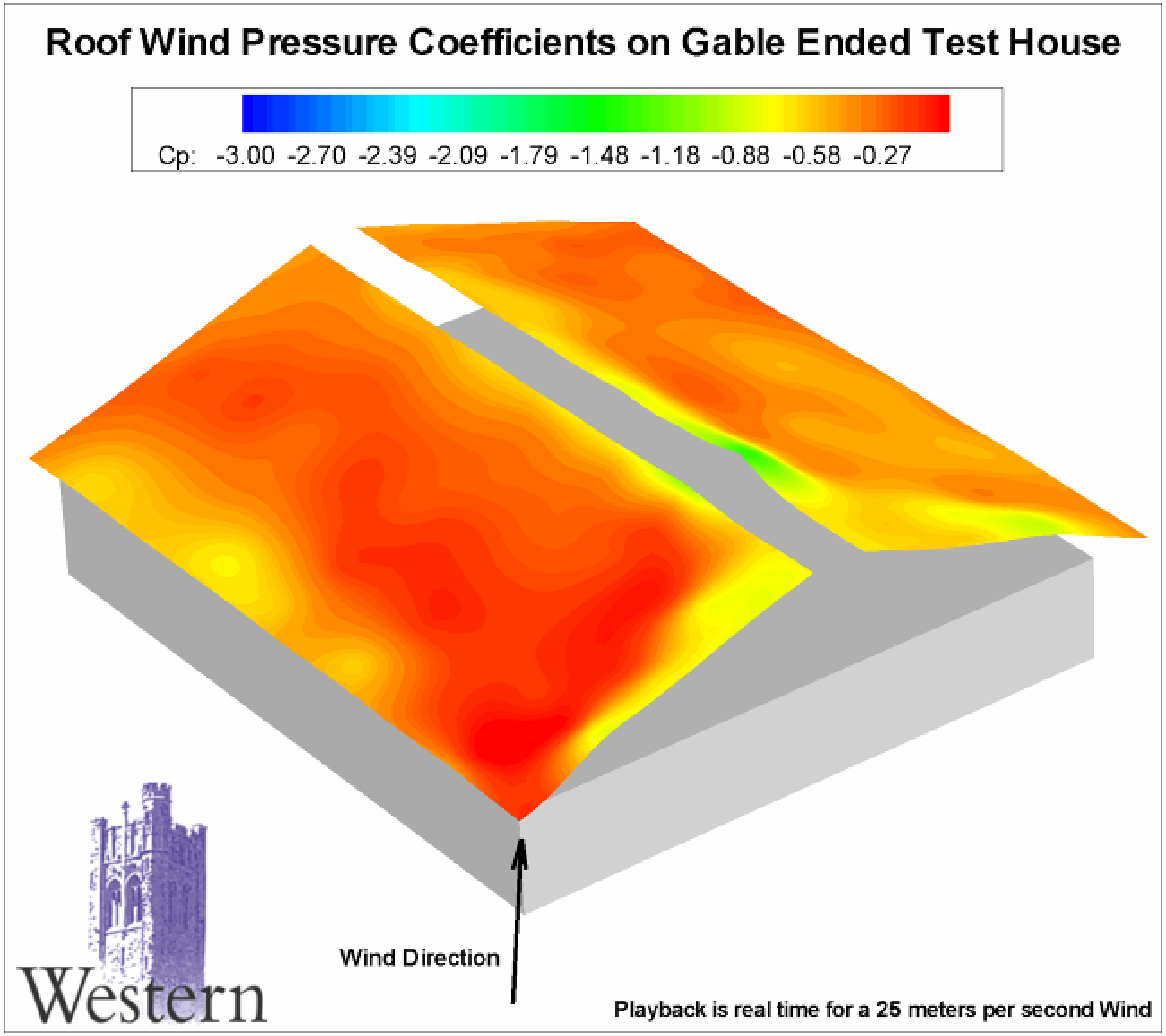
Measured PLA performance is outstanding!





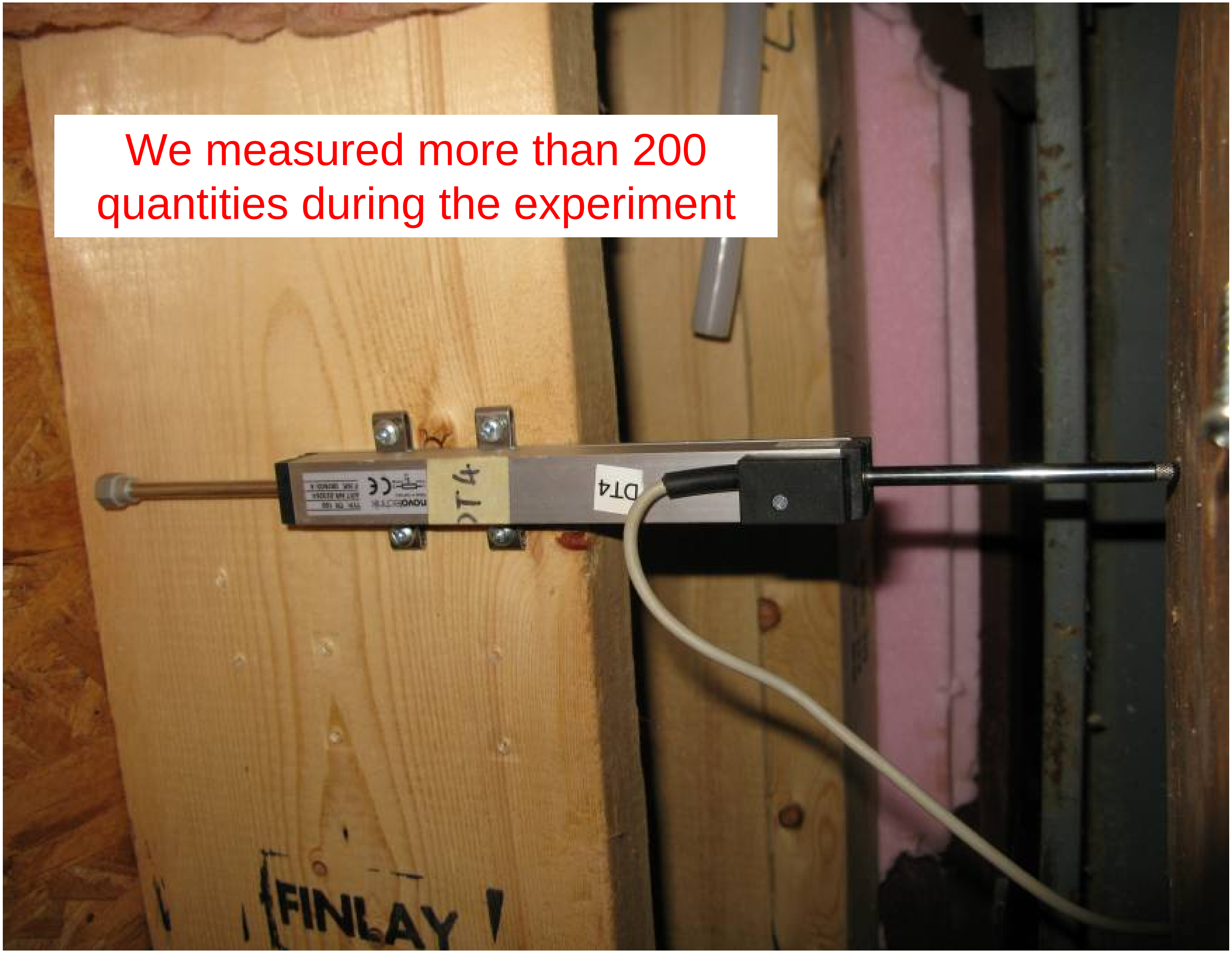
Wind tunnel pressure time histories and the actual measured trace obtained using the PLA on a 4 ft x 4 ft area (left).

The applied time varying force on the 12 ft x 22 ft test wall due to 10 PLAs compared with the measured reactions. It is clear that overall loads are well replicated! (right)

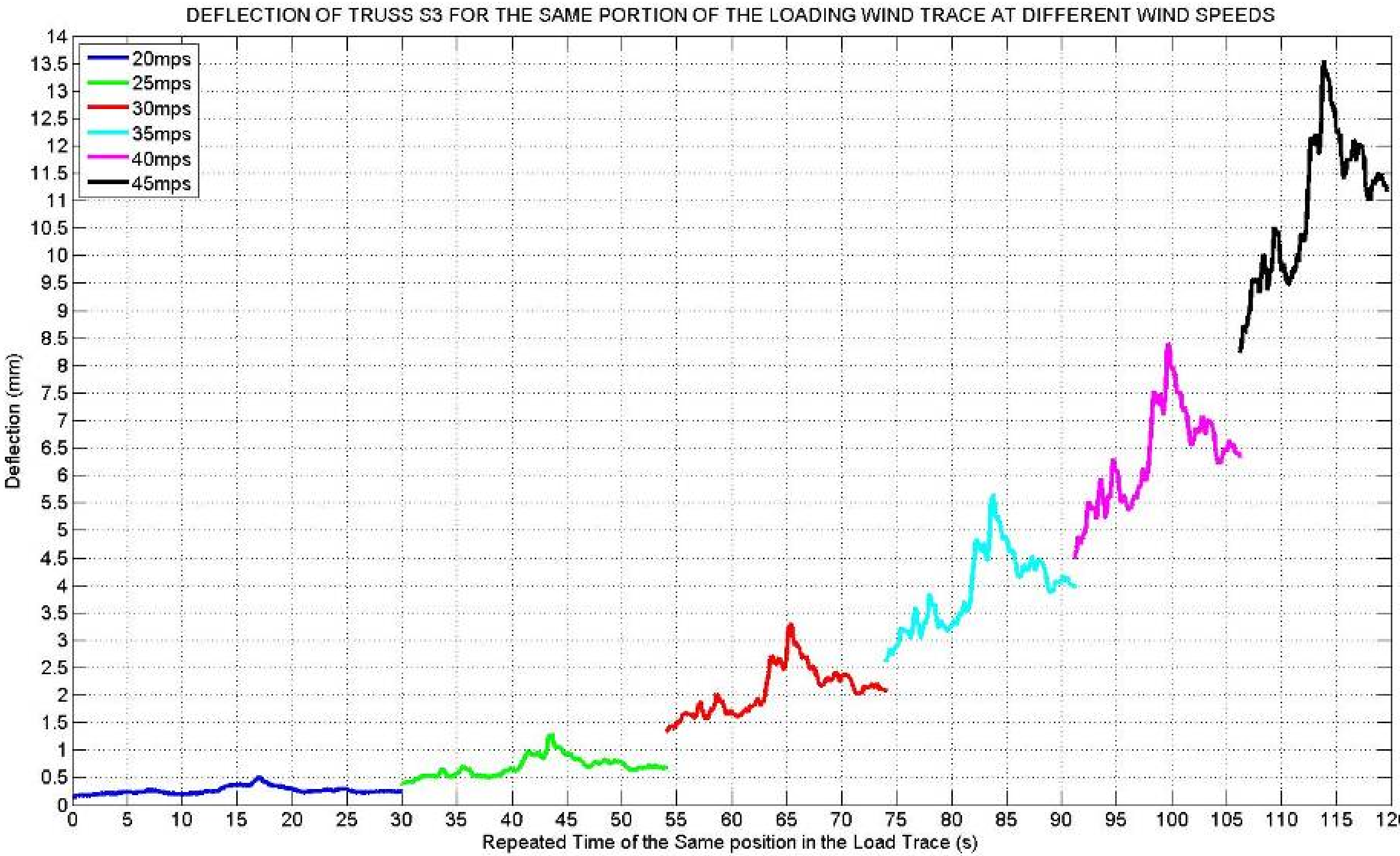


Roof Wind Pressure Coefficients on Gable Ended Test House
Cp: -3.00 -2.70 -2.39 -2.09 -1.79 -1.48 -1.18 -0.88 -0.58 -0.27
Wind Direction
Western
Playback is real time for a 25 meters per second Wind

We measured more than 200 quantities during the experiment



RESULTS


DEFLECTION OF TRUSS S3 FOR THE SAME PORTION OF THE LOADING WIND TRACE AT DIFFERENT WIND SPEEDS
20mps
25mps
30mps
35mps
40mps
45mps
Deflection (mm)
Repeated Time of the Same position in the Load Trace (s)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
8
8.5
9
9.5
10
10.5
11
11.5
12
12.5
13
13.5
14
0
5
10
15
20
25
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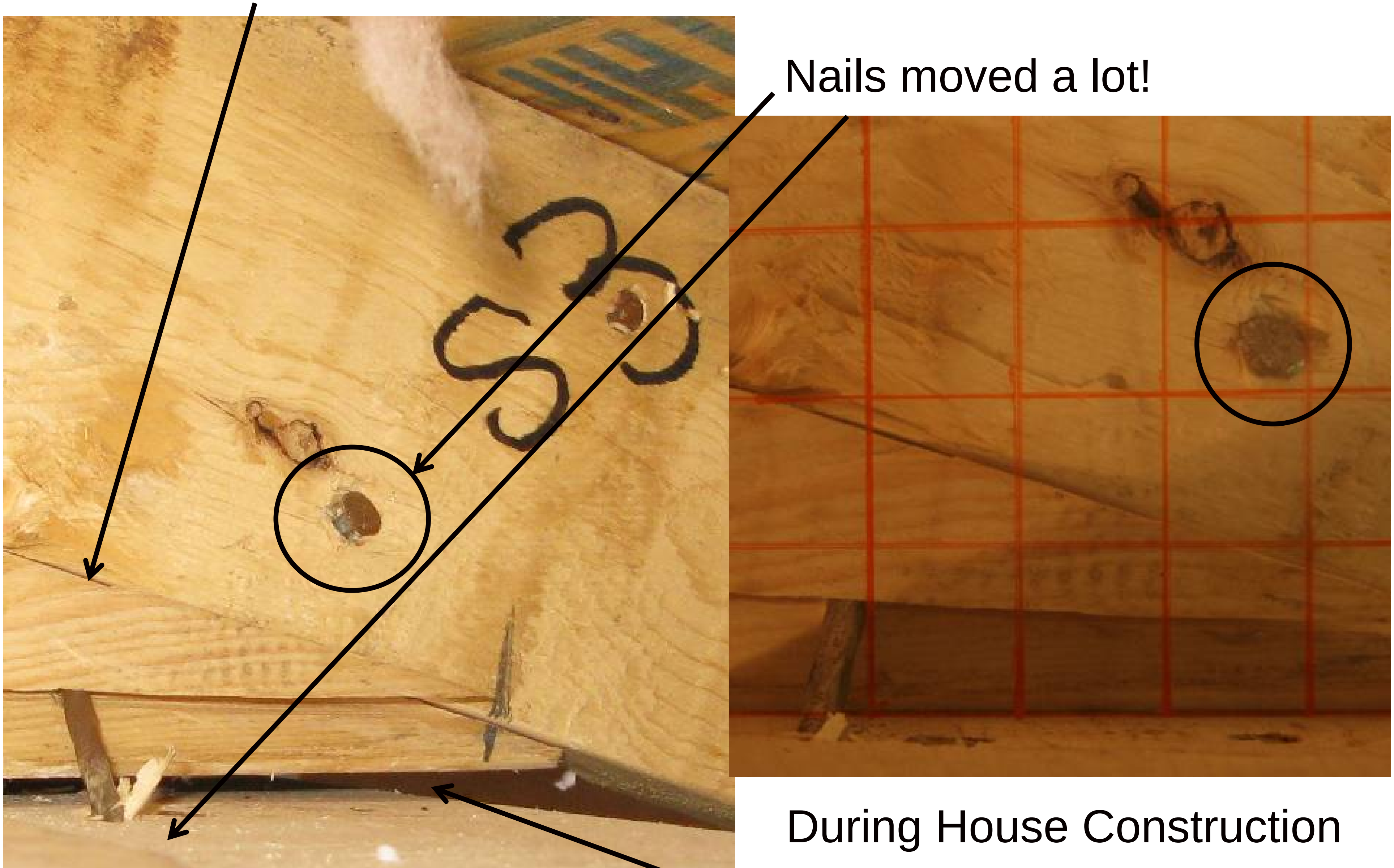
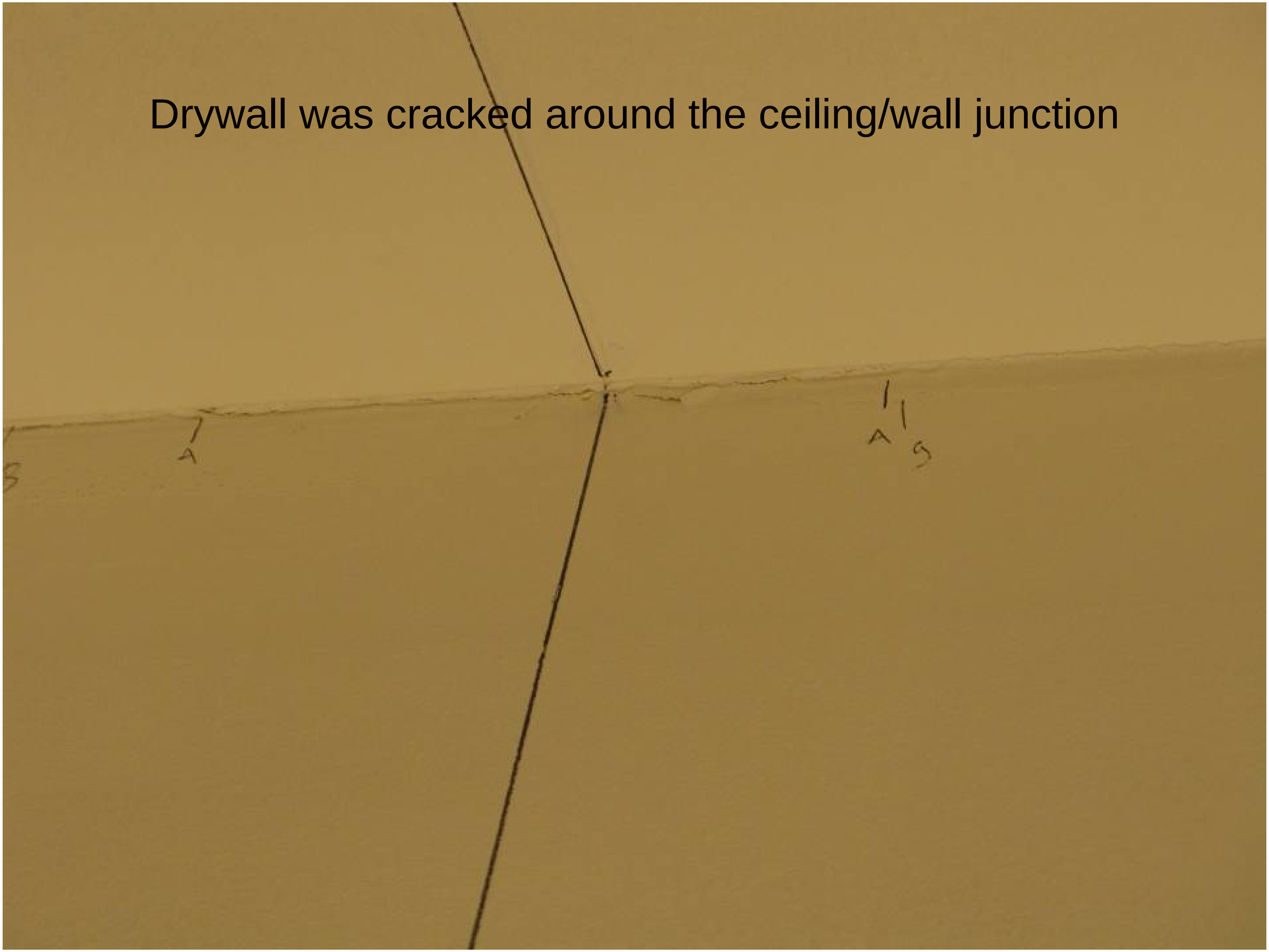
95
100
105
110
115
120



After Dynamic Test #3

During House Construction

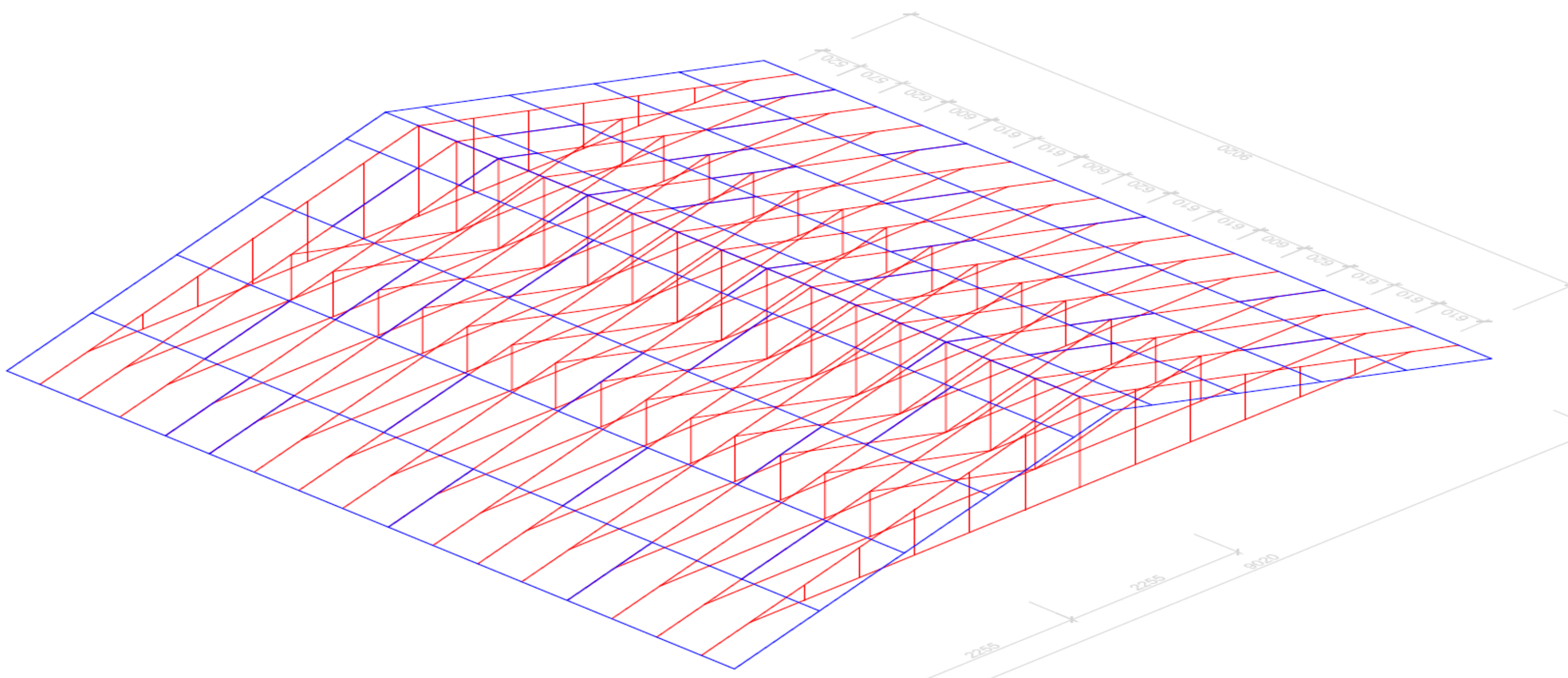
Drywall was cracked around the ceiling/wall junction



3D Modeling of Light Frame Wood Roof

- 3D numerical model of test house roof is under development
- To be used with nonlinear dynamic analysis under spatio-temporal wind loading

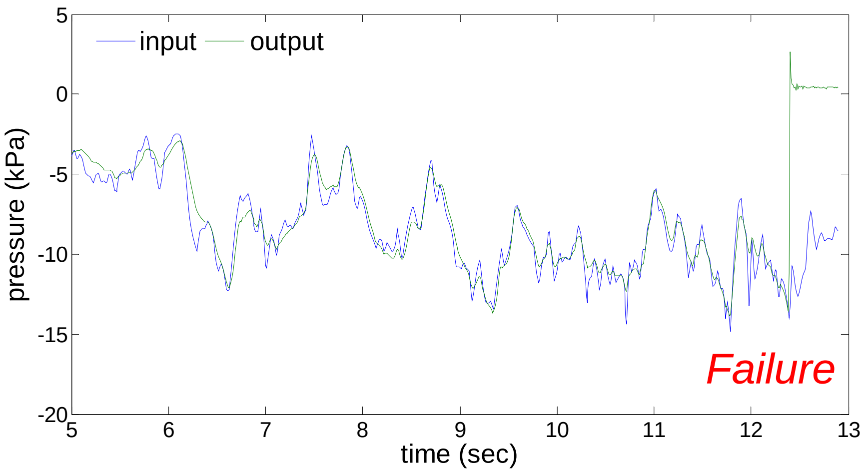
Bob He, H.P. Hong



This is not a great design solution, despite low cost

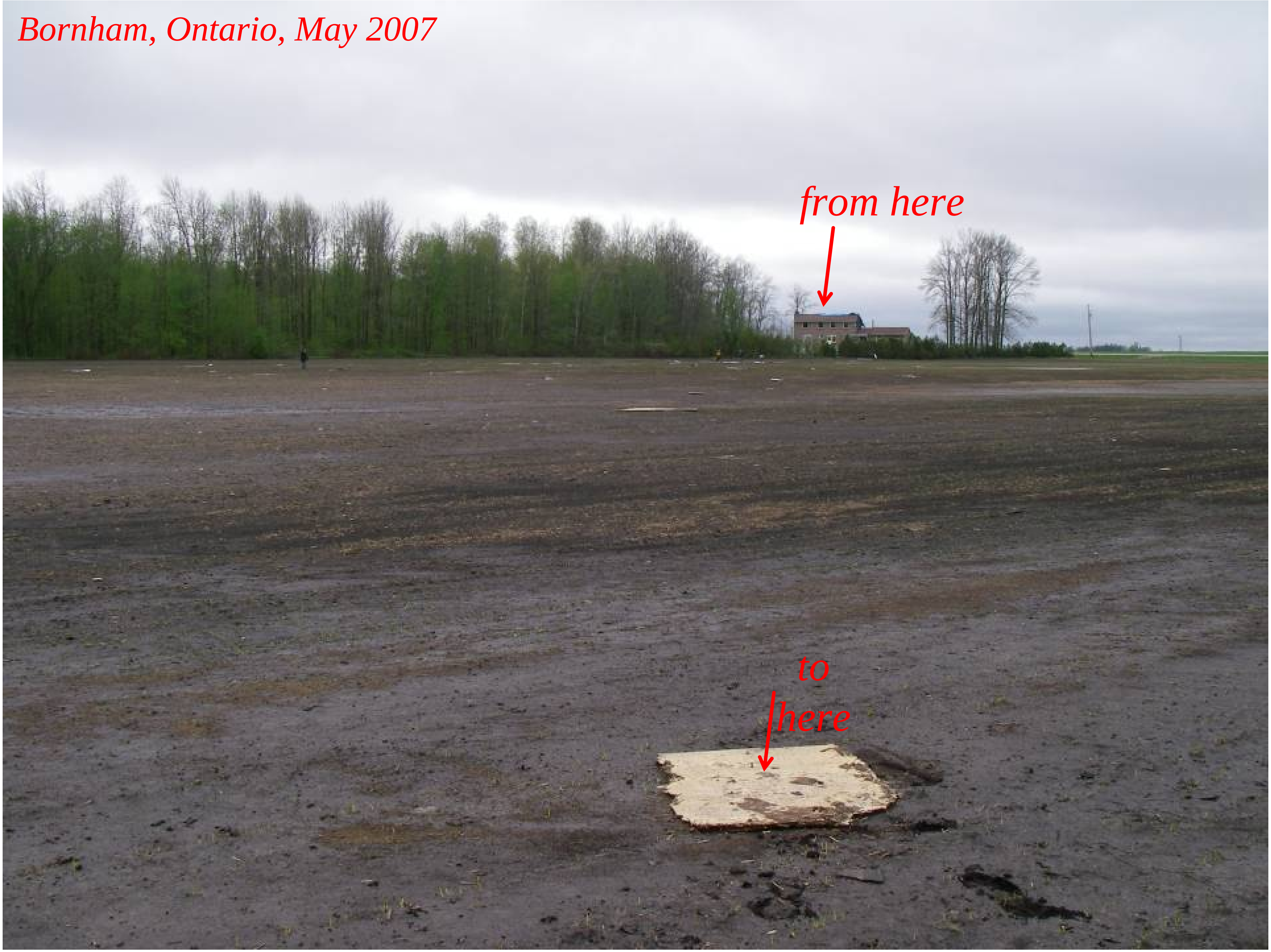
Component tests are also being done at 3LP

Example: investigation of the behaviour glass plates under realistic fluctuating wind loading



Wind-borne Debris

Elie, Manitoba. F5

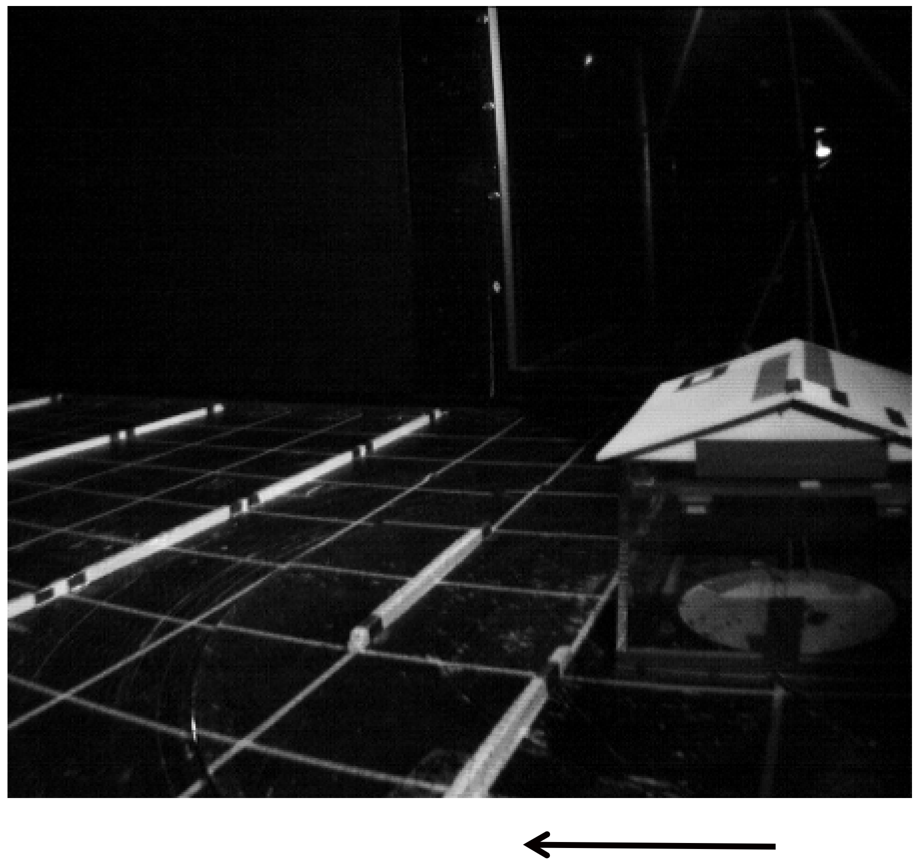

Bornham, Ontario, May 2007
from here
to
here


Documenting hold
down details are
critical to our analysis

Failure model in the wind tunnel

Flight of Plywood Sheathing

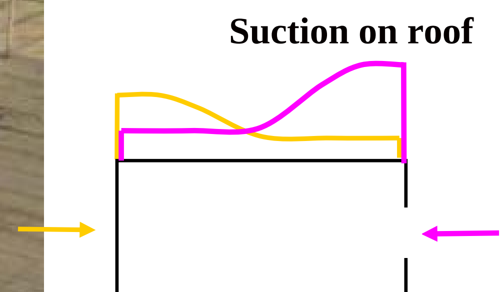
Initial Overturning Failure and subsequent autorotational motion



Internal Pressures

Examples of building damage due to wind-induced internal &external pressures:

Air hangar building damaged during Hurricane Juan, Nova Scotia, 2003.



Peak C_{pi} = 20 ~ 70% of $\hat{C}_{pe}$ on Roof

Summary

UWO has a new full-scale testing facility to study and mitigate the effects of extreme winds in a realistic, cost-effective and efficient way.

We are able to simulate up to Cat. 5 hurricane wind loads on entire structures, repeatably and realistically.

Our overall program involves all significant effects of wind on low-rise structures, and we have all of the tools in place to study these effects:

- *full-scale structural and component tests with realistic wind loads*
- *industry-standard structural and component tests*
- *wind tunnel tests (wind loads, internal pressures, and wind-borne debris)*
- *3D finite element modeling of wood frame structures*
- *air cannon debris impact tests*
- *post-event damage surveys*

Using the new technology for testing, which makes use of detailed wind tunnel data, we can unambiguously relate the wind loads to building codes and industry standard test results.

With the same data we can apply loads to portions of structures appropriately. Thus, we can ‘calibrate’, and even upgrade, industry standard tests with these more realistic tests.

Thus, code loads and component and/or structural responses can be unambiguously linked to the true loads allowing for optimization in design of products for hurricane regions with a level of risk consistent with the code (or any other) requirements.

With these tools we can examine effects of errors in installation and account for them.

All of this leads to optimal design for cost effective and realistic wind damage mitigation strategies.

This project would not have been successful without outstanding students:

Murray Morrison,
David Henderson &
Eri Iizumi
did most of this!

F5, Elie, Manitoba. June, 2007