In-field Observations of Damage and Building Resilience: With Examples

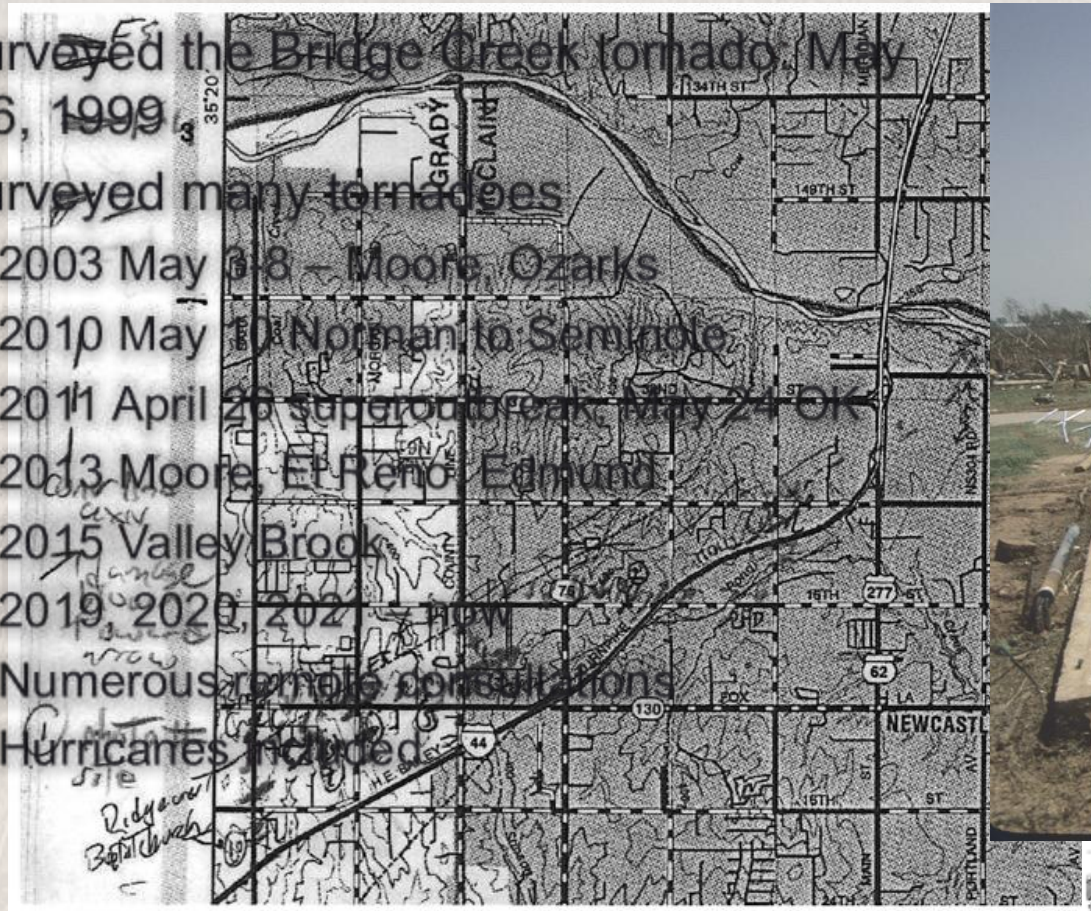
James LaDue

01 October 2025

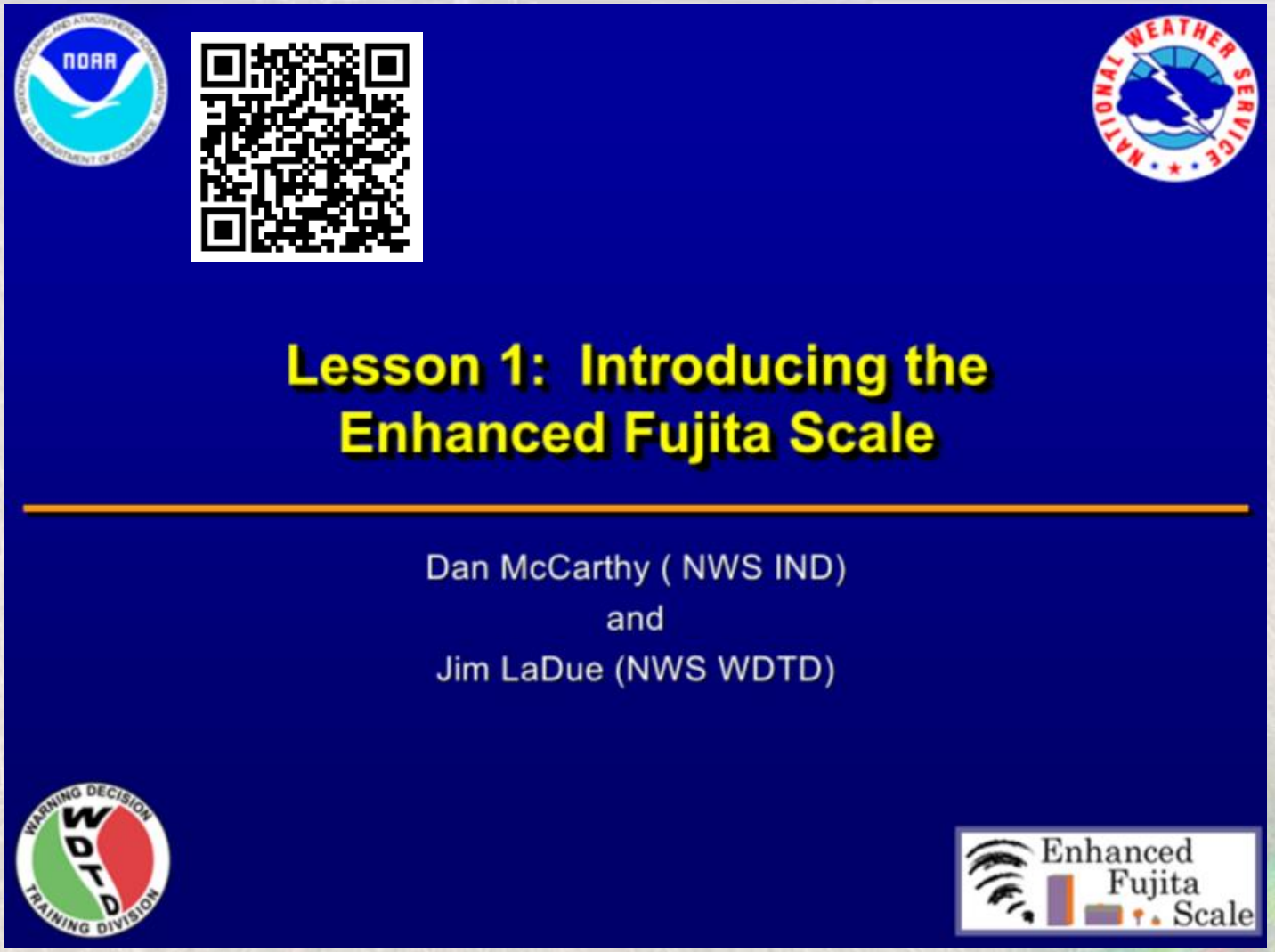
SCIPP Hazard Resilient Buildings Workshop

A Bit on my History

- I've always been obsessed with severe storms -
  - Surveyed the Bridge Creek tornado, May 4-6, 1999
  - Surveyed many tornadoes
    - 2003 May 8 – Moore, Ozarks
    - 2010 May 10 Norman to Seminole
    - 2011 April 26 supercell outbreak, May 24 OK
    - 2013 Moore, El Reno, Edmund
    - 2015 Valley Brook
    - 2019, 2020, 2021 now
    - Numerous remote consultations
    - Hurricanes included



EF Scale Deployment in 2007



https://training.weather.gov/wdtd/courses/damage-surveying/index.php

The EF Scale

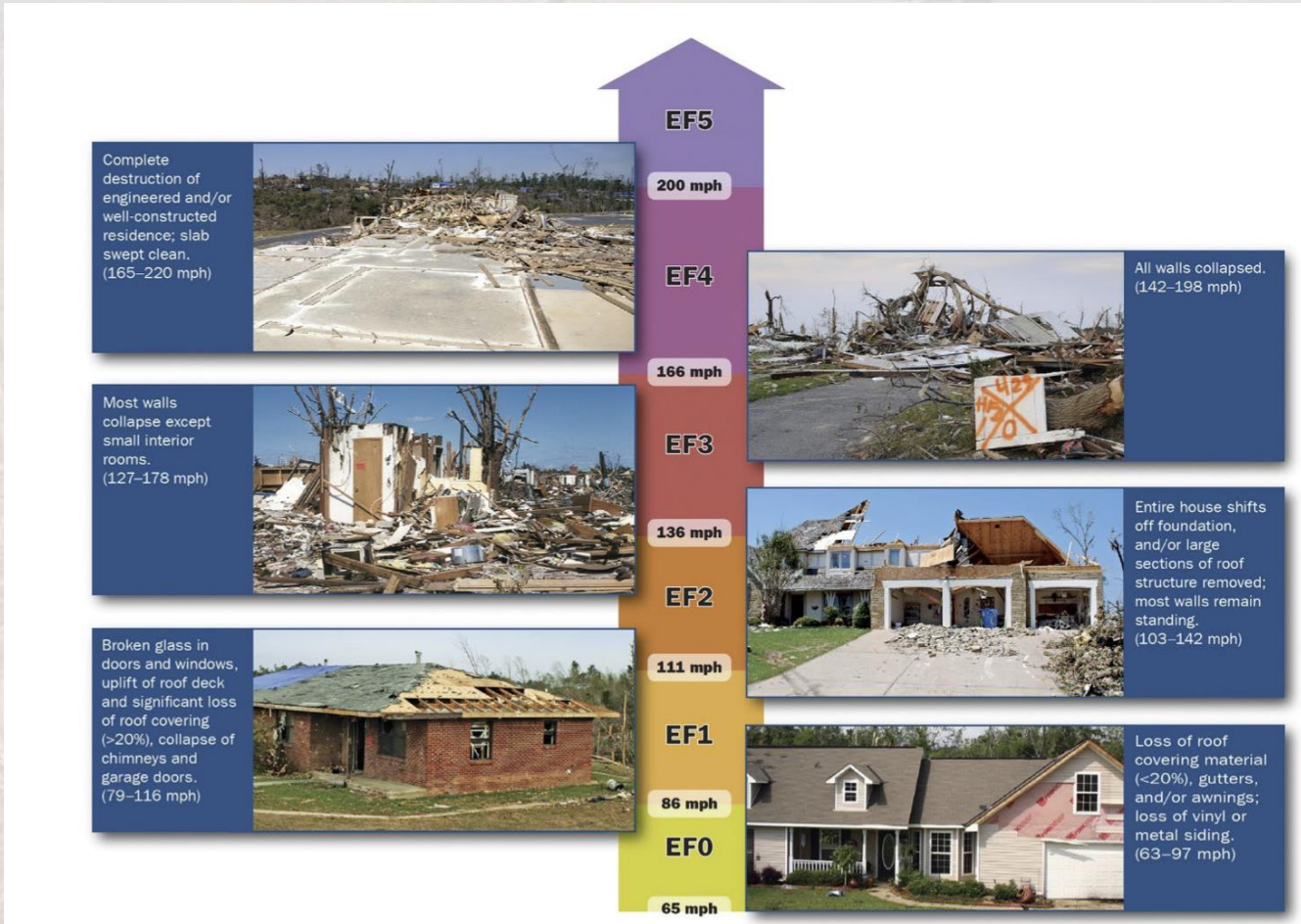
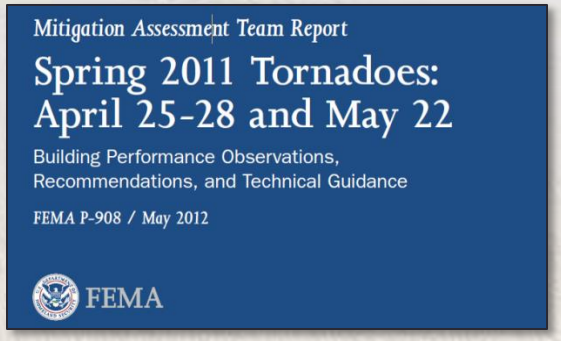


Figure 2-1: Typical tornado damage according to the EF Scale (wind speeds are estimated 3-second-gust wind speeds)

SOURCE: NOAA NWS, STORM PREDICTION CENTER

My Learning Points Over the Years

- The EF Scale Has Significant Flaws
- There are Several Other Methods to Bear in Evaluating Tornado Intensity
- We can improve the tornado climatology
- Improved survivability can only come from stronger shelters
- The meteorology community can help but this is a big problem to solve

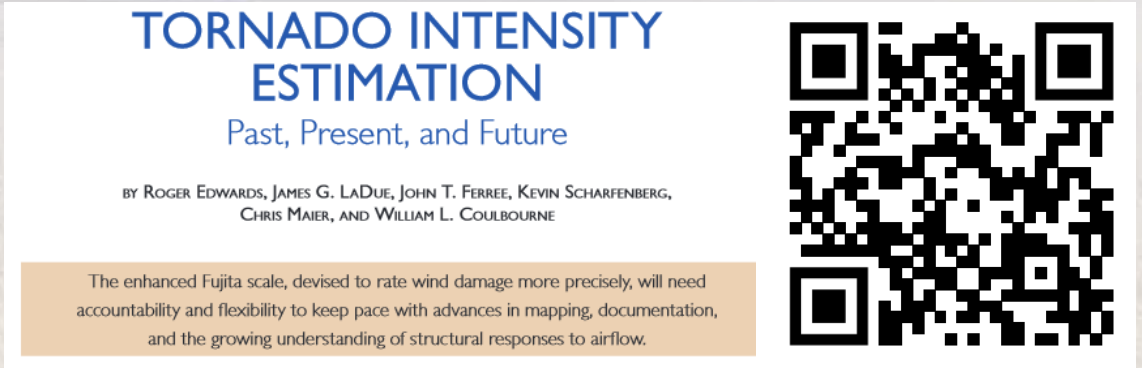


#40 - DI lists incomplete
#41 – DOD categories inadequate
#42 – gradient of DODs
#43 – Incorrect order of DODs
#44 – lacking photographic DOD guidance
Differences between NWS and FEMA

Finding 7: Lacking adequate DIs and DODs

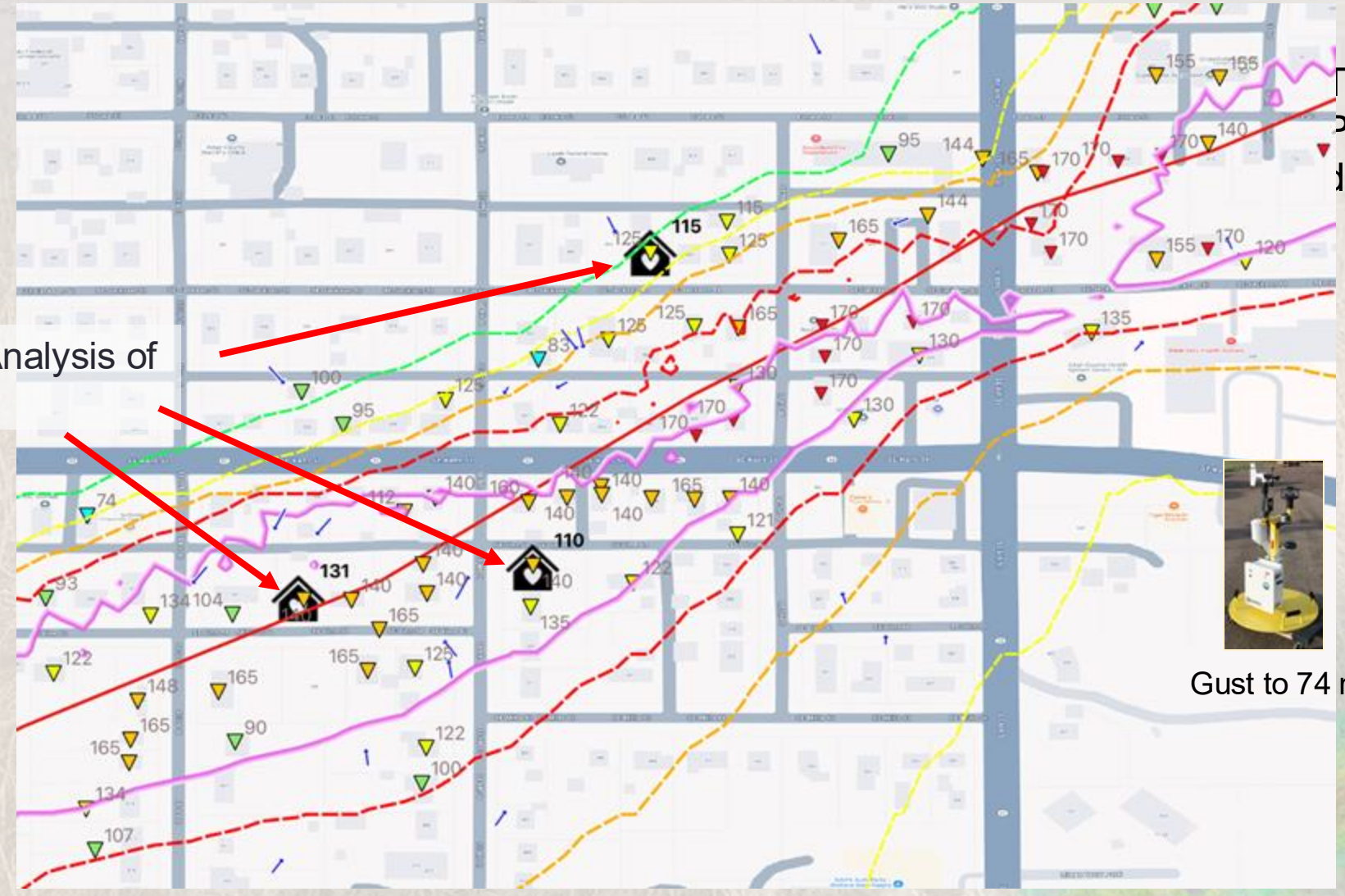
Taking Action on These Problems

- Published the status of the EF scale
- Created an ASCE Standards committee on wind speed estimation, branded with the AMS
- Co-created an AMS Committee on Engineering Resilient Communities



The New Standard on Wind Speed Estimation is Coming

Forensics Analysis of buildings



Tree-Fall Pattern Analysis derived winds

Gust to 74 mph

EF5	201 mph
EF4	166 mph
EF3	136 mph
EF2	111 mph
EF1	86 mph
EF0	60 mph

Teaching the Communicators About Resilient Construction

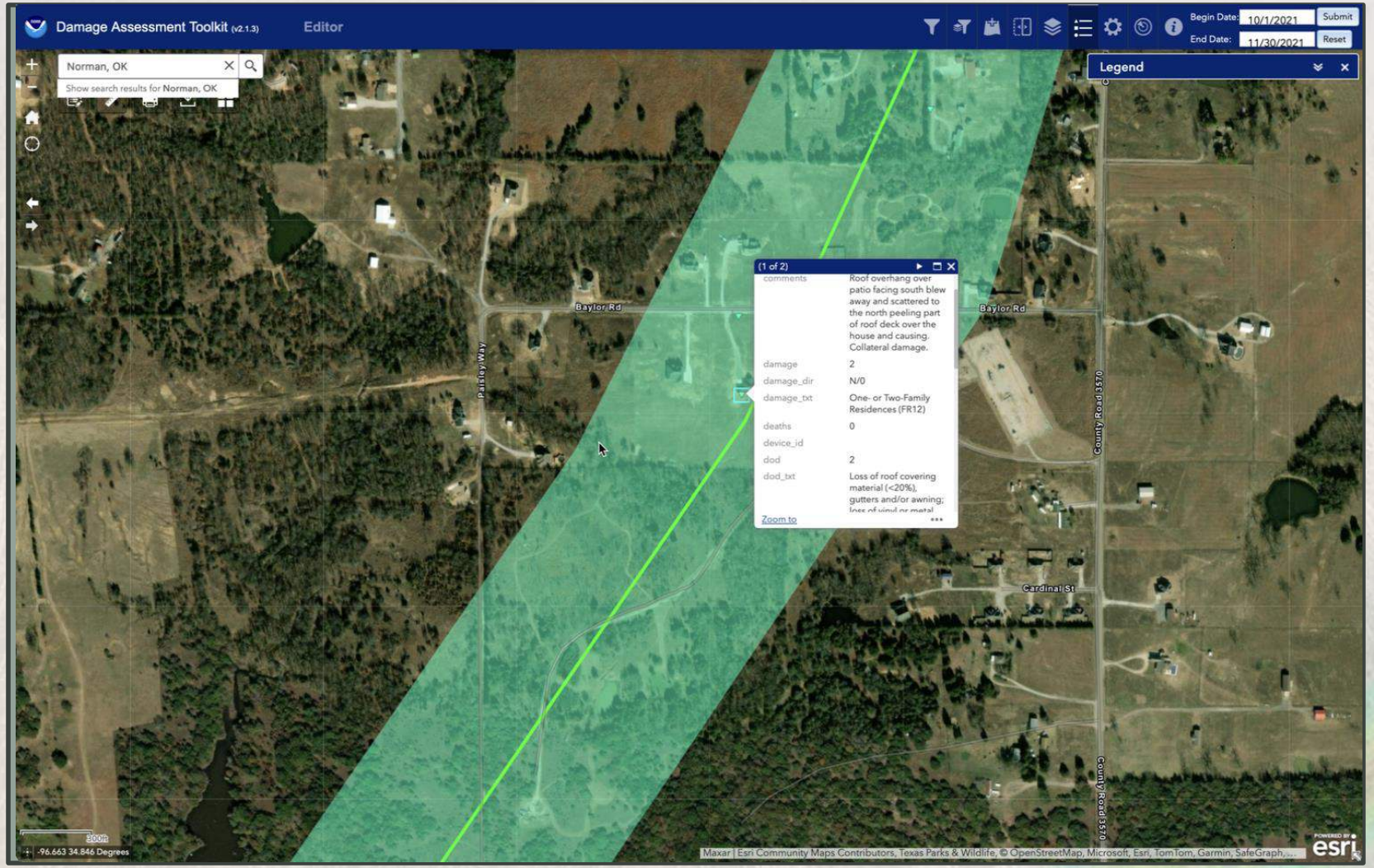
With All That, How Do I Handle What I See in the Field?

Consider the House DI

DOD*	Damage description	EXP	LB	UB
1	Threshold of visible damage	65	53	80
2	Loss of roof covering material (<20%), gutters and/or awning; loss of vinyl or metal siding	79	63	97
3	Broken glass in doors and windows	96	79	114
4	Uplift of roof deck and loss of significant roof covering material (>20%); collapse of chimney; garage doors collapse inward; failure of porch or carport	97	81	116
5	Entire house shifts off foundation	121	103	141
6	Large sections of roof structure removed; most walls remain standing	122	104	142
7	Exterior walls collapsed	132	113	153
8	Most walls collapsed, except small interior rooms	152	127	178
9	All walls	170	142	198
10	Destruction of engineered and/or well constructed residence; slab swept clean	200	165	220

* DOD is degree of damage

Case 1: 10 Oct 2021 North of Ada, OK



Case 1: 10 Oct 2021 North of Ada, OK

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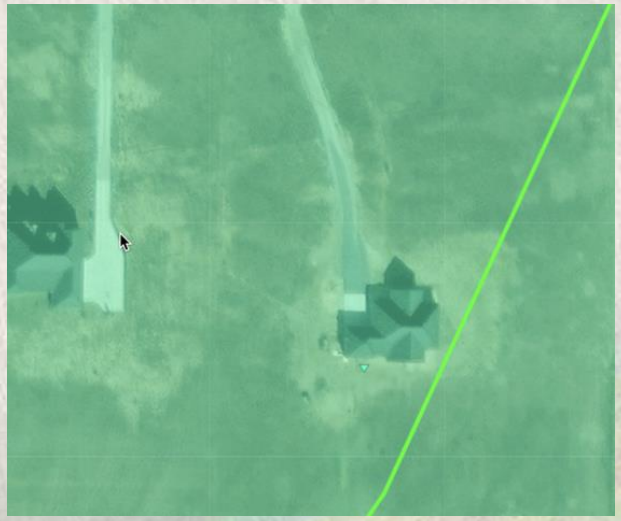
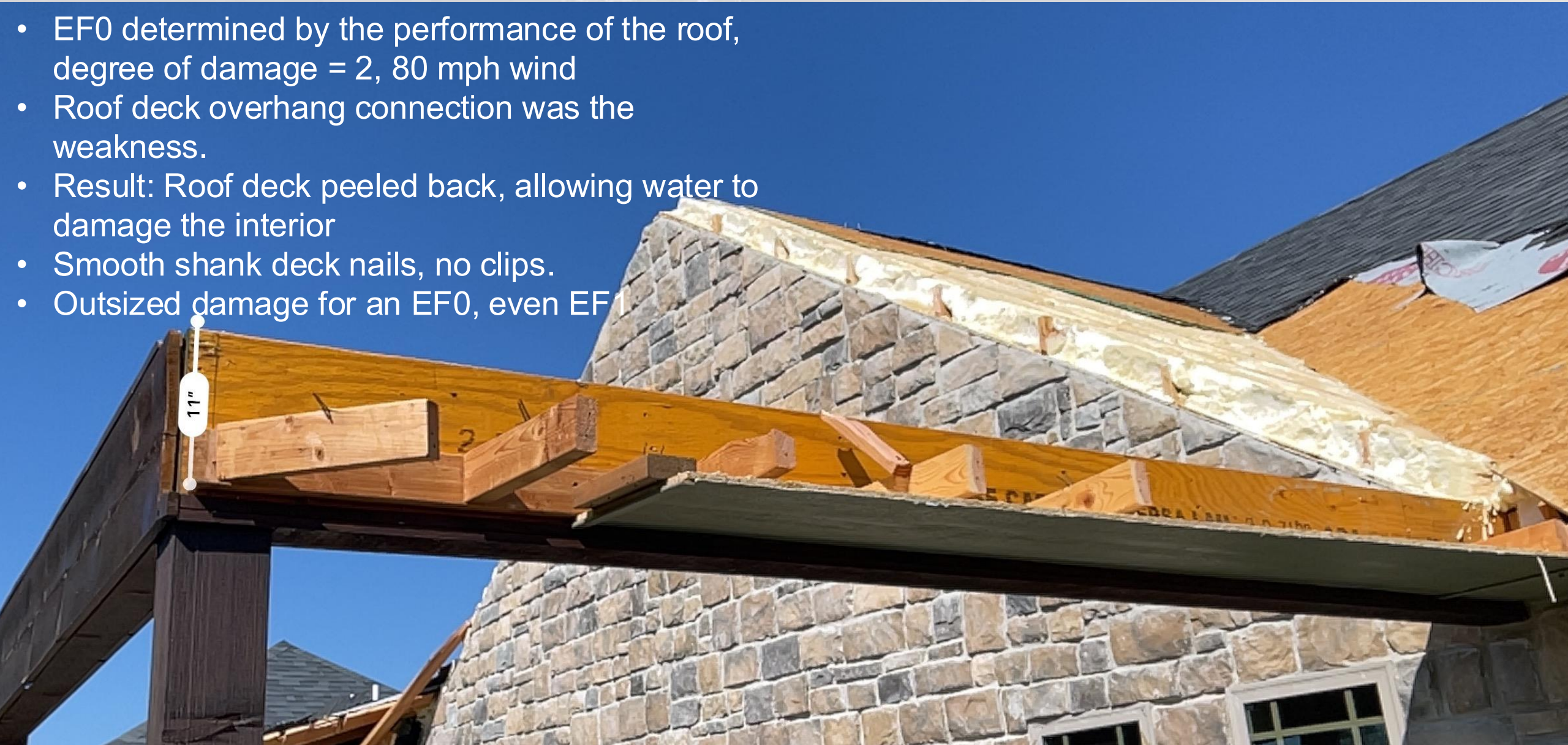


Case 1: 10 Oct 2021 North of Ada, OK

- EF0 determined by the performance of the roof, degree of damage = 2, 80 mph wind
- Roof deck overhang connection was the weakness.
- Result: Roof deck peeled back, allowing water to damage the interior
- Smooth shank deck nails, no clips.
- Outsized damage for an EF0, even EF1



What happened here?

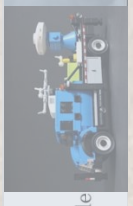
Moore, OK 2015

Photo by James G. LaDue

Closer

Photo by James G. LaDue

Very close



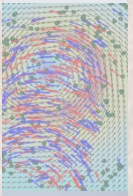



Photo by James G. LaDue

Closer

- Degree of Damage 4: Uplift of roof deck > 20%
- Home followed Moore's new 130 mph code, except for…
- The stapled roof deck
- Guess where the damage occurred?
- 110 mph EF1 assigned in 2015
- Lower winds are likely

Photo by James G. LaDue

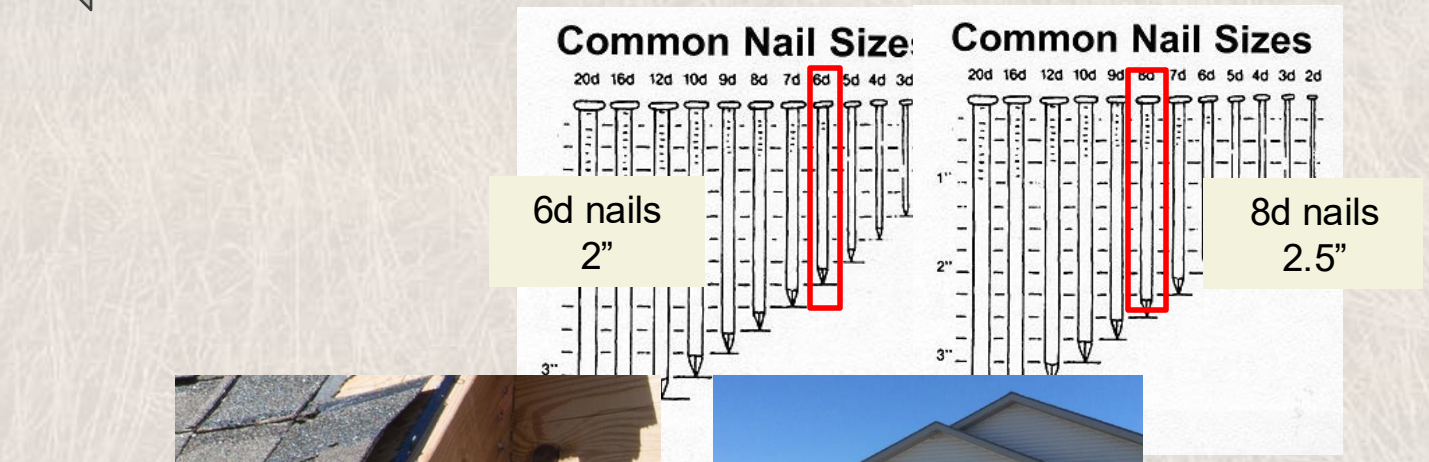
DoD 4: Spectrum of Roof Deck/Garage Doors Resistance

DOD 4: Uplift of roof deck and loss of significant roof covering material (>20%); collapse of chimney; garage doors collapse inward; failure of porch or carport

81 mph

97 mph

116 mph



6d nails
2”

8d nails
2.5”

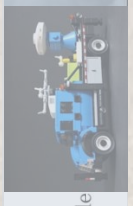
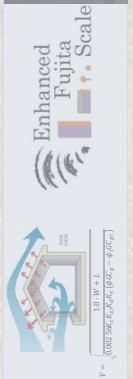
Stapled roof deck
Missing deck nails

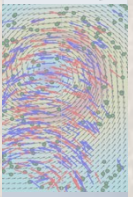
Standard garage doors <4 braces

Fortified or similarly sealed roof deck

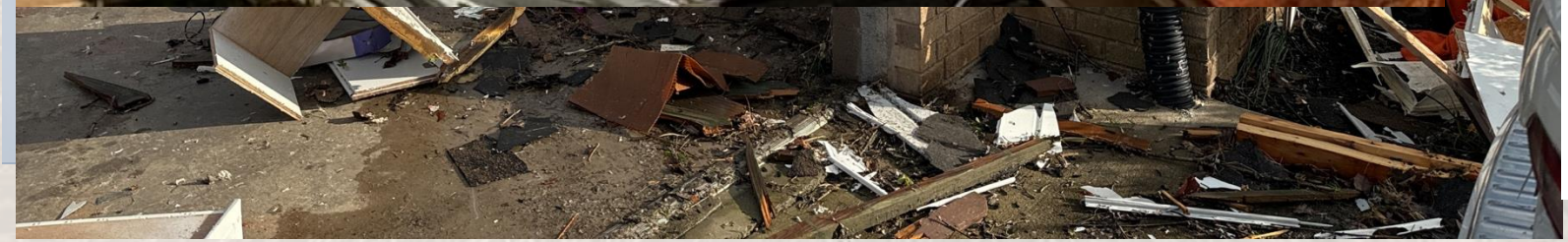
Wind-rated garage doors 7 braces

What About Higher Degrees of Damage?




DoD 7-9: Failure of Walls or a Slider?



Tornado | TSTM/Wind | Tropical Wind | Flood

Office: OHX Event ID: Clarksville QC'd: ☑

Storm Date: 12/9/2023 19:42 HH:MM

Survey Date: 12/10/2023 15:07 HH:MM

DI: One- or Two-Family Residences (FR12)

DoD: Entire house shifts off foundation

Windspeed(mph): ☐ Missing

103 — 120 — 141

EF Rating: EF2 Damage Direction: N/A

Injuries: 0 Fatalities: 0

This house did not exhibit a rigid slide. It disassembled. Still, go with LB EF3. Would've been EF4 had there been bolts or overlapping rigid sheathing with floor.

This is a DoD 5: Slider

- This Slider is classic. The weak spot was the floor diaphragm with the foundation.
- House then slid as a body, but lost its roof.
- House was rated with the roof or as a slider
- Result = EF2.

Figure 4. Example showing a home that was "swept clean" from its foundation that was rated EF-2 based the removal of its roof. Note vehicle remained within the destroyed garage.

Marshall, T. P., McCarthy, D., & Ladue, J. (2008, October). Damage survey of the Greensburg, KS tornado. Paper presented at the 24th Conference on Severe Local Storms, Savannah, GA. Boston, MA: American Meteorological Society. https://ams.confex.com/ams/pdfpapers/141534.pdf

DoD 10: Failure of Walls: Case 2

EF5: if this house had structural sheathing overlapping wall and bottom floor, or toe-nailed studs to floor.

Storm Date: 4/26/2024 20:45 HH:MM

Survey Date: 4/27/2024 20:31 HH:MM

DI: One- or Two-Family Residences (FR12)

DoD: All walls collapsed

Windspeed(mph): Missing

142 — 167 — 198

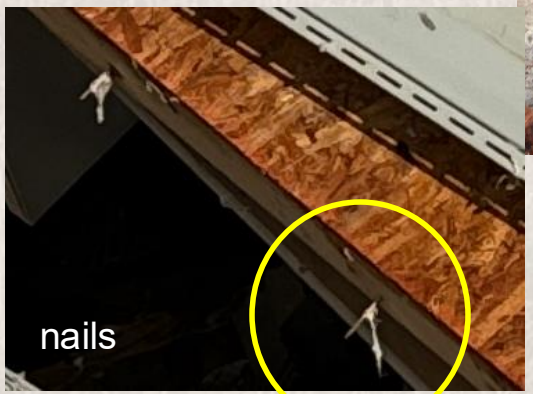
EF Rating: EF4 Damage Direction: N/A

Injuries: 0 Fatalities: 0

Comments: All walls collapsed. Foundation was swept clean of nearly all debris. Home built and inspected within past 2 years. Primary connector from floor to walls were nails. Sill plate bolted to poured foundation.

DoD 7-9: Spectrum

113 mph	132 mph	153 mph
127 mph	152 mph	178 mph
142 mph	170 mph	198 mph



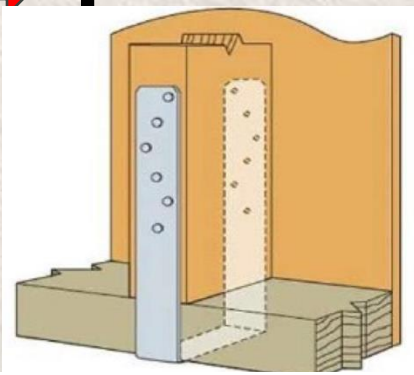
8d nails

6d nails

Shot pins

Bolts with nuts and standard washers

Bolts +rigid sheathing overlapping Bottom Plate



SBP Double Wrap

Strap wraps around bottom of base plate and is nailed to stud on either side

DoD10: EF5 in Moore, OK

Tornado | TSTM/Wind | Tropical Wind | Flood

Office: OUN Event ID: QC'd:

Storm Date: 5/20/2013 19:56 HH:MM

Survey Date: 5/24/2013 15:21 HH:MM

DI: One- or Two-Family Residences (FR12)

DoD: Destruction of engineered and/or well constructed residence; slab swept clean

Windspeed(mph): Missing

165 — 200 — 220

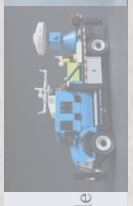
EF Rating: EF5 Damage Direction: UNKNOWN

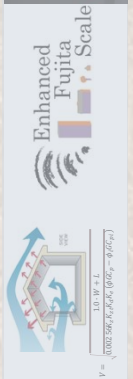
Injuries: 0 Fatalities: 0

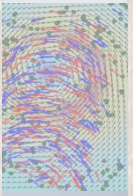
Comments: Sill plates bolted with nuts and washers. Toenailing of walls noted. Bent bolts.

Anchor bolts, toe-nailed studs to bottom plates. Likely corner sheathing only.

Success Stories



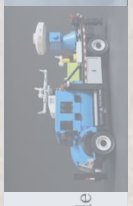




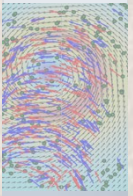
DoD 6: Above Code Roof

- 26 Feb 2023, Norman
  - Built 2020
  - EF2 damage to trees yet minimal shingle damage
  - 130 mph code
  - Rafter clips, reinforced decking inc. adhesive insulation
  - DoD=3, windows broken

Another Above Code Case: Lady Lakes, FL, 2007






- Vehicle blown into doorway
- Built in 2006
- Post-Andrew building code
  - https://stantec.maps.arcgis.com/apps/MapSeries/index.html?appid=a053ac48343c4217ab4184bc8759c350
- DoD 4: Max wind speed estimate not enough with current EF scale. But EF2 estimate is a sufficient start.

Uplift of roof deck and significant loss in roof covering.

https://www.weather.gov/media/tbw/2007/SumterCountyTornado.pdf

Cost Effectiveness – Moore, OK

Simmons, Kovacs & Kopp (2015)
Weather Climate and Society

- Engineering estimate of a direct reduction of 30% in damage for homes built post Moore code
  - Using an estimate from the Florida study, this corresponds to a full loss reduction of 46%
- Estimate of $3 in reduced damage for each $1 in increased cost (based on direct reduction only)

AUSTIN COLLEGE

Common Inconsistent Damage Patterns

Inconsistent Damage Behavior: walls

19 April 2023 – Goldsby, OK Selah neighborhood

- Unbraced gable ends are weaknesses
- Walls popped out due to weak connections and internal pressure increase due to broken windows.
- Temptation would be to go with DoD7 ”**exterior walls collapsed**”.
- However, shingle loss is minimal. Caution may say go with DoD 6 “**Large sections of roof structure removed, most walls remain standing**”.

Inconsistent Damage Behavior: Roof vs Walls

- 26 Feb 2023 Norman
- Steel reinforced concrete walls.
- Cold formed steel roof rafters.
- Weak roof-to-wall connection.
- This is a DoD 6 with a lower-than-expected wind assigned ~115 mph EF2.

- This was just southwest of the success story.

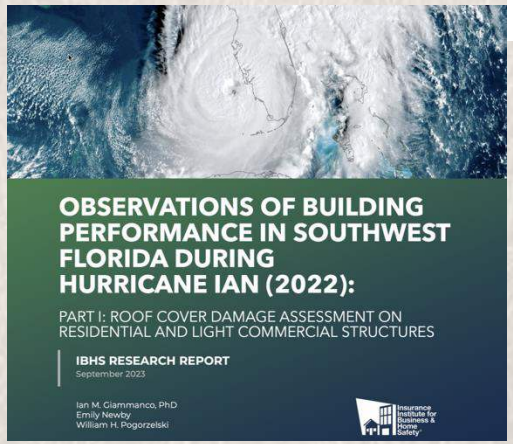
Inconsistent Damage: The Garage Door

- Shawnee, OK 19 April 2023
- Picture faces north.
- Assigned DoD 7 “Exterior Walls Collapsed” 132 mph.
- Garage door blew in and overpressure removed adjoining walls and roof.
- Rest of the roof has little shingle damage.
- Suggest DoD 6, 120 mph or DoD 7 same wind speed.

Shingle Roof Age and Effect on Damage: Applies to More than Roofs

- A report following Hurricane Ian

https://ibhs1.wpenginepowered.com/wp-content/uploads/Building-Performance-during-Hurricane-Ian.pdf



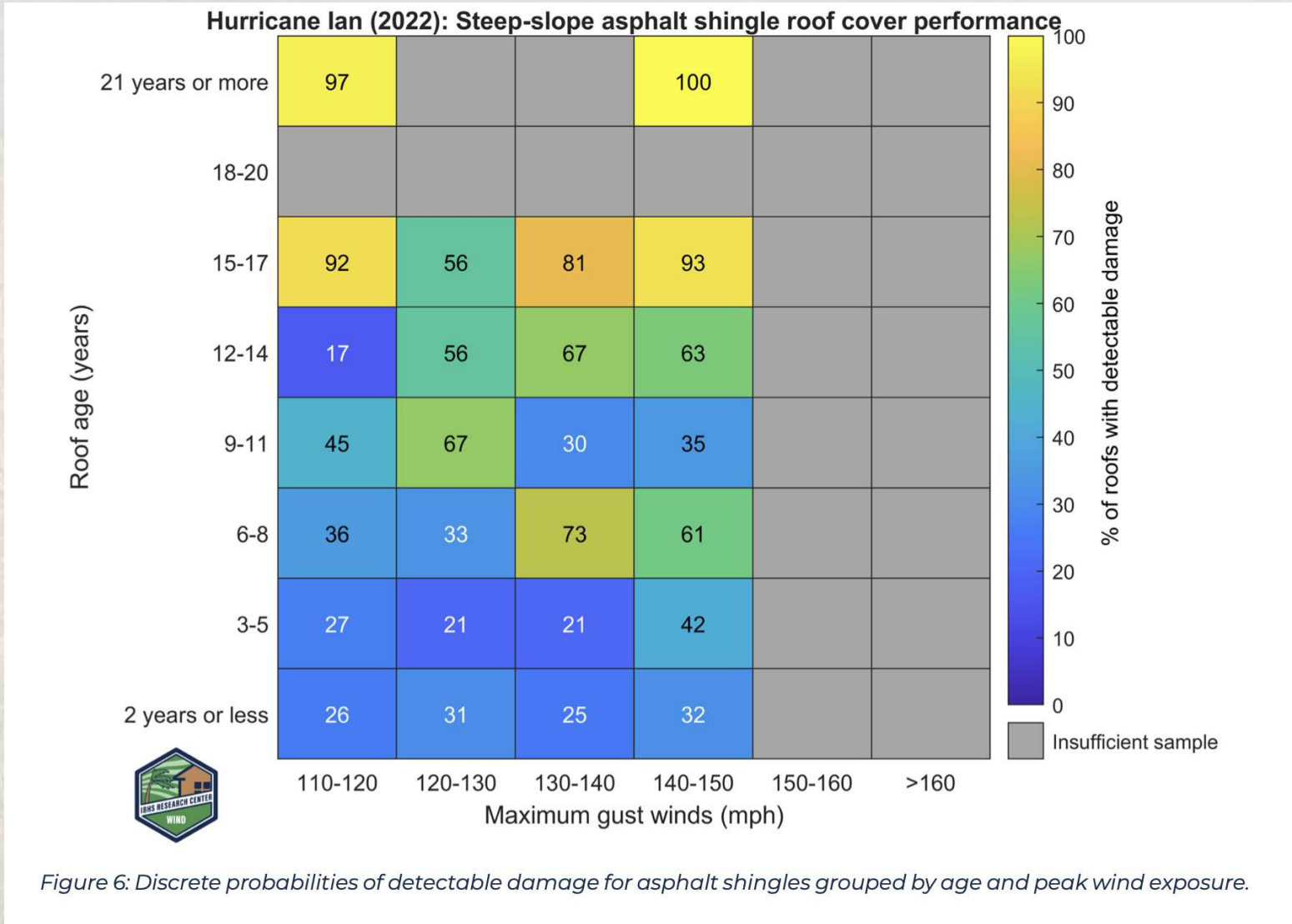
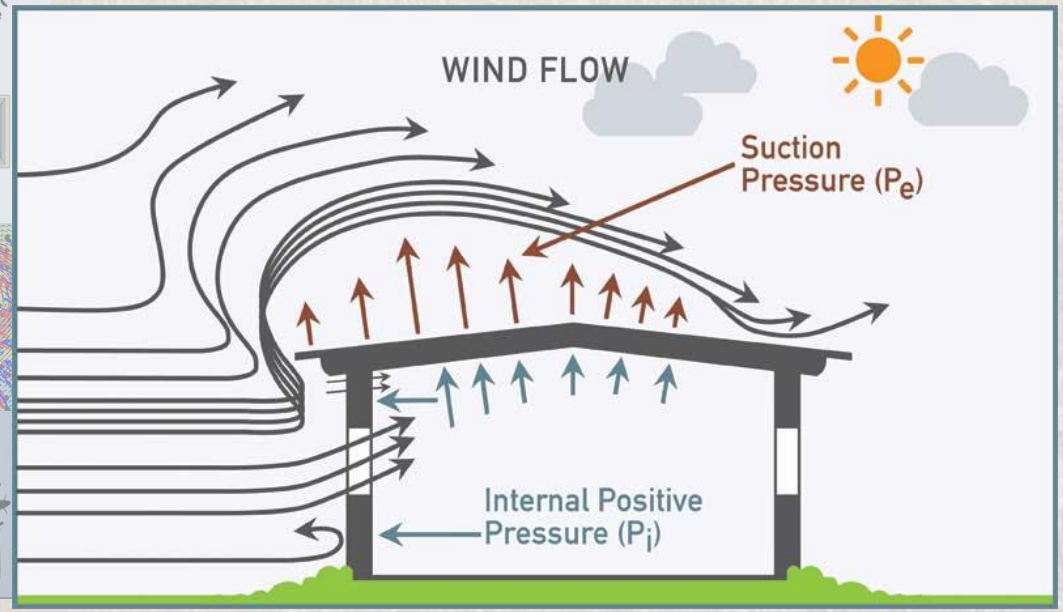
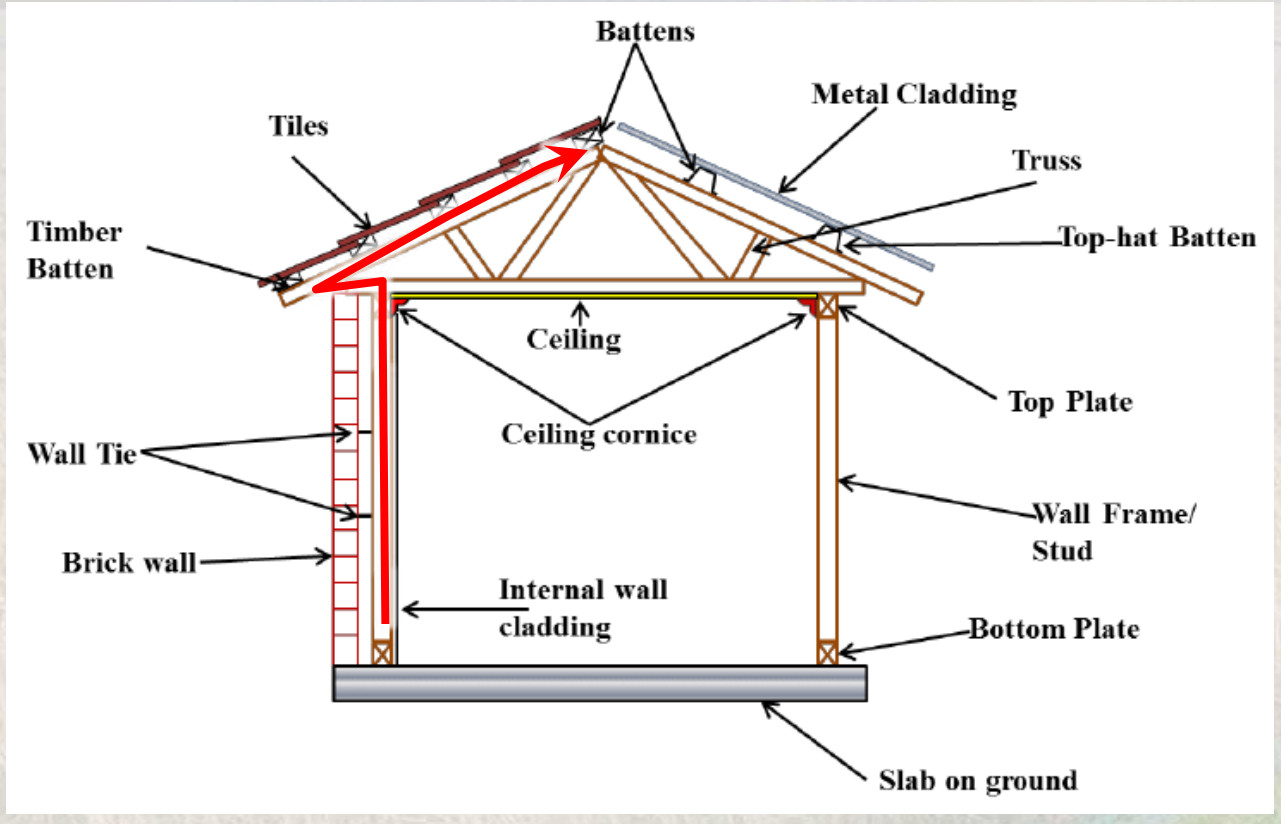


Figure 6: Discrete probabilities of detectable damage for asphalt shingles grouped by age and peak wind exposure.

Basic house Load Path

- https://youtu.be/MbZIvaM35h8?si=XqwzQLqdsieIUMEh
- https://youtu.be/lxdFh8nYMgM?si=Tw9J-YrX8w79VWVQ





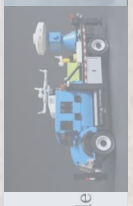
Damage occurring anywhere in the load path weakens the rest

Discussion Points

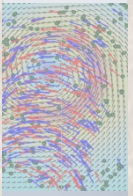
- Most housing is insufficient to protect property inside of houses in EF1 or greater.
- But there are success stories and the Moore 2014 130 mph code saves $$$.
- New construction is adopting some best practices but weaknesses remain.
- The science of wind speed estimation is moving forward, a new standard is coming

- Contact Information
  - James.G.LaDue@noaa.gov

topics



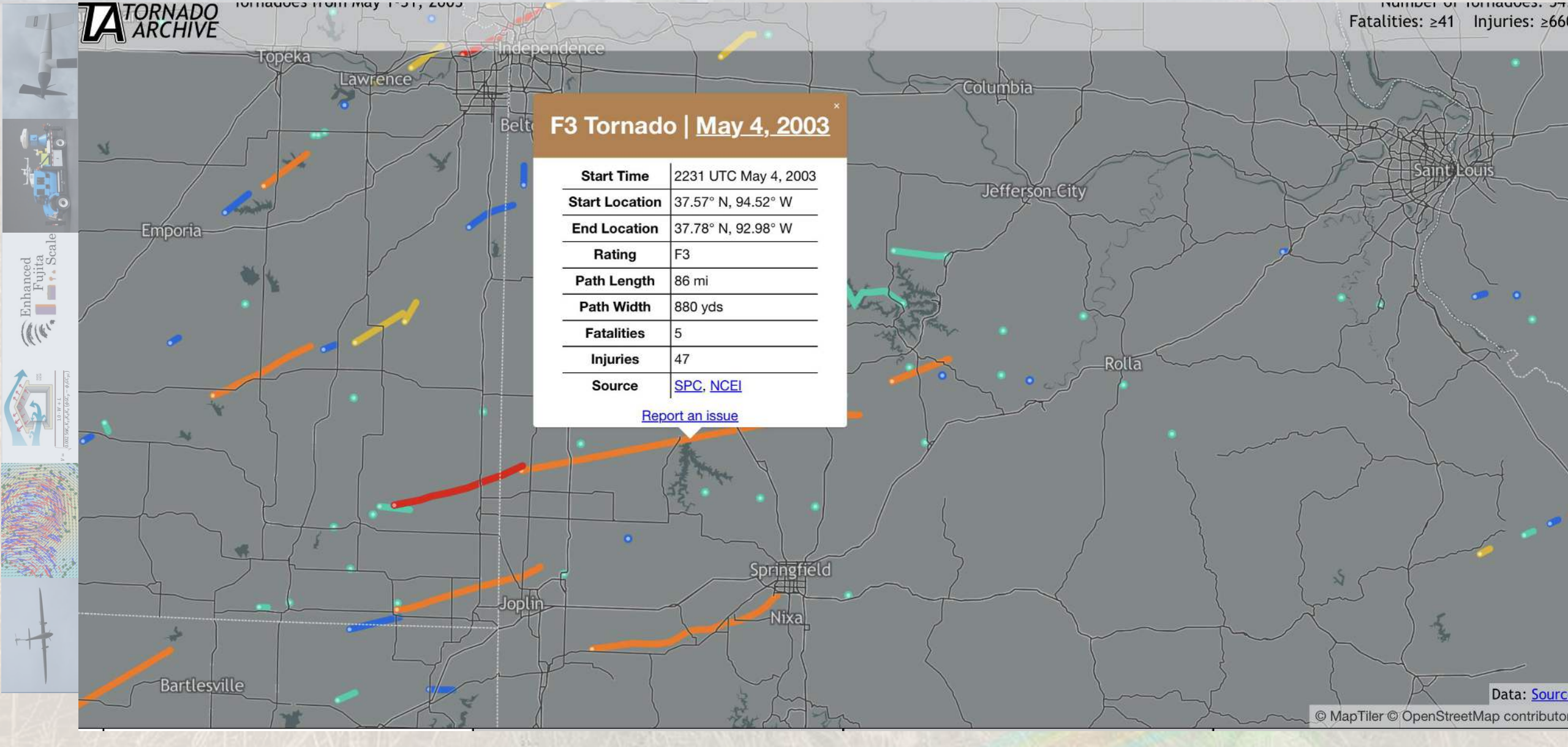



Goal: Convey lessons learned in good and bad building performance from field surveys

- Stories of how I got here
  - Designed and taught EF Scale course
  - Learned its flaws
  - Set up stakeholder's group then ASCE
  - Had to do something about weak homes
  - Co-started AMS resilient communities
  - led start of AMS short course in resilient construction
  - Involvement in NWIRP

- Signature cases in learning about resilience
  - October 2020
  - 26 Feb 2023 Norman – Two adjacent houses, wildly different outcomes
  - 26 Apr 2024 Elkridge, NE – northern construction's major flaw
  - 19 April 2023 – impact of age on building resistance
  - Examples of Florida's resistant building codes (Lady Lakes 2007, Hurcn Milton 2024
  - Hurricane Ian – 2023: importance of preventing rainwater intrusion.
- In general, how I view building components vs wind speed
- Importance of load path, not every building part works in isolation
- Where we go from here WRT tornado intensity estimation
- How do we spread the message about improving tornado/windstorm resilience?

2-4 May 2003


TORNADO ARCHIVE
Fatalities: ≥41
Injuries: ≥66
Topeka
Lawrence
Independence
Columbia
Jefferson City
Saint Louis
Emporia
Rolla
Springfield
Joplin
Nixa
Bartlesville
F3 Tornado | May 4, 2003
Start Time 2231 UTC May 4, 2003
Start Location 37.57° N, 94.52° W
End Location 37.78° N, 92.98° W
Rating F3
Path Length 86 mi
Path Width 880 yds
Fatalities 5
Injuries 47
Source SPC, NCEI
Report an issue
Enhanced Fujita Scale
Data: Sourc
© MapTiler © OpenStreetMap contributo

2007: Lady Lakes, FL, the 1st EF-rated Tornado Day

The EF scale provided a significant improvement in guidance.

We found a big improvement in updated codes but legacy homes were no shelter. More later.

01 March 2007 – Enterprise & Millers Ferry, AL: The first EF4 Tornado

TORNADO ARCHIVE

Tornadoes from Mar 1-31, 2007

Number of Tornadoes: 172
Fatalities: 27 Injuries: 169

I found the tree DIs did not reflect the latest science.

The enterprise school failed the students due to lack of continuous load paths.

Montgomery

Dothan

Data: Sources

© MapTiler © OpenStreetMap contributors

2011: Super Outbreak,

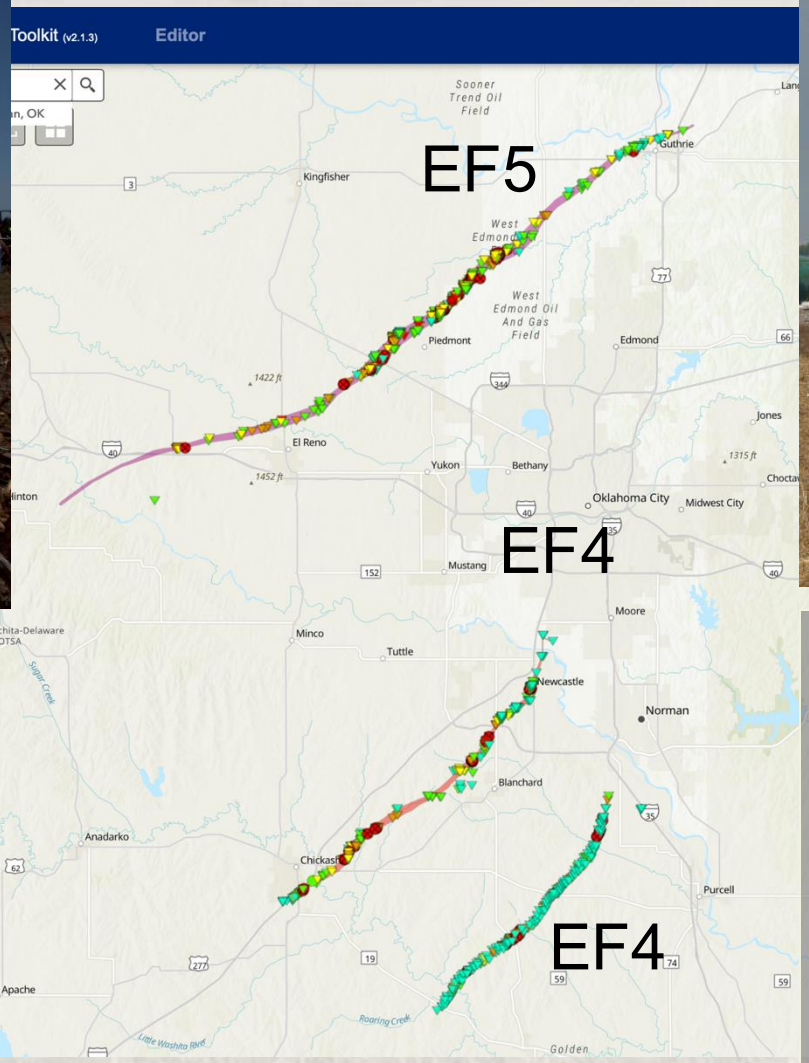
There was disagreement between rating decisions between NWS, NSF, FEMA.

People heeded warnings but their homes failed them.

Photo by Jim LaDue

Damage imagery provided by National Ocean Service

2011 May 24: OK Tornado Outbreak:



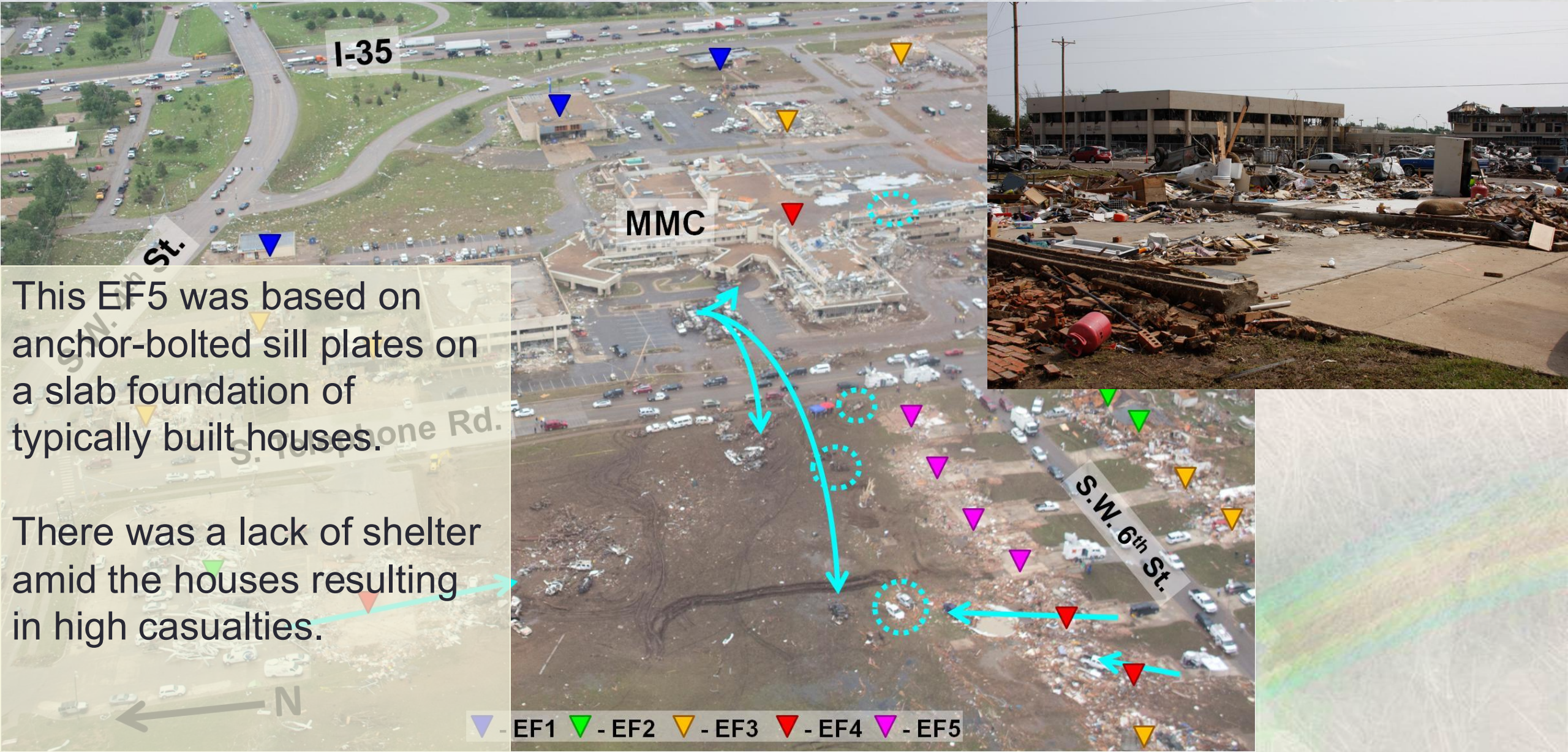
This only EF5 was based on radar and the drilling rig.

A reinforced concrete dome house provided shelter had the residents walked into the bathroom.

20 May 2013: The Last EF5

The Damage Assessment Toolkit and the EF scale's design allowed 4000 data points to be logged by a collaboration between the NWS, NSSL and WDTD. See https://doi.org/10.1175/WAF-D-14-00039.1
and
https://doi.org/10.1175/BAMS-D-14-00033.1
and
https://doi.org/10.1175/MWR-D-14-00357.1

20 May 2013: The Last EF5



This EF5 was based on anchor-bolted sill plates on a slab foundation of typically built houses.

There was a lack of shelter amid the houses resulting in high casualties.