Current Research Towards Tornado-Resilient Communities

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Acknowledgements

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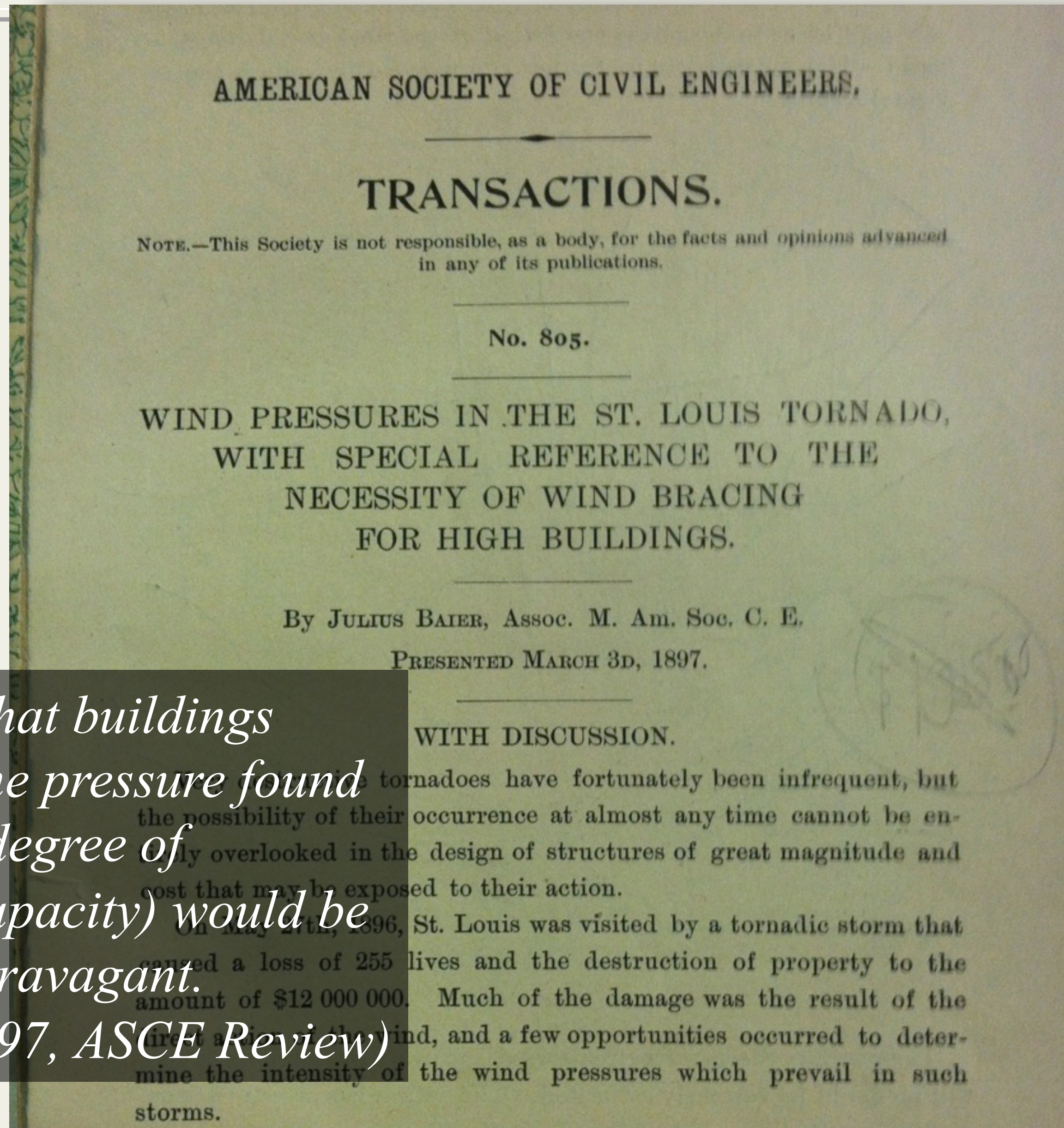
Questions on Our Minds

- Tornado effects on buildings – what is known?
  - How are buildings damaged by tornadoes?
  - Are specific buildings more vulnerable than others?
  - Can damaged buildings stifle community progress?

- Tornado-resilient building design - is it feasible?
  - What knowledge is needed to build such buildings?
  - Are our building materials/technology suitable?
  - What trade-offs are needed, or should we change?

120 years of Tornado Damage Surveys


AMERICAN SOCIETY OF CIVIL ENGINEERS.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

No. 805.

WIND PRESSURES IN THE ST. LOUIS TORNADO, WITH SPECIAL REFERENCE TO THE NECESSITY OF WIND BRACING FOR HIGH BUILDINGS.

By JULIUS BAIER, Assoc. M. Am. Soc. C. E.

PRESENTED MARCH 3D, 1897.

WITH DISCUSSION.

... tornadoes have fortunately been infrequent, but the possibility of their occurrence at almost any time cannot be en... ...ly overlooked in the design of structures of great magnitude and cost that may be exposed to their action.

On May 27th, 1896, St. Louis was visited by a tornadic storm that caused a loss of 255 lives and the destruction of property to the amount of $12 000 000. Much of the damage was the result of the direct ... the wind, and a few opportunities occurred to determine the intensity of the wind pressures which prevail in such storms.

It is scarcely possible that buildings would yield to any of the pressure found by Mr. Baier, and that degree of provision (structural capacity) would be neither difficult nor extravagant.

(1897, ASCE Review)

TORNADO FORCES
AND THEIR EFFECTS ON BUILDINGS

By

MICHELE G. MELARAGNO

FOREWORD

DR. MELARAGNO'S paper deals with a subject of great importance to the people of Kansas, and indeed to all those who live in the United States east of the Rocky Mountains. The fury of the tornado and the devastation left by these violent storms is held in fearful awe. Even the early settlers in the Plains States took the precaution to build "cyclone cellars" to protect their lives. Present day warning systems operated by local communities in coordination with the ESSA Weather Bureau have been a tremendous help in reducing the loss of life when these storms strike our ever growing centers of population.

Still, as Dr. Melaragno points out, little concern has been shown in an effort to reduce property damage in the path of these storms. Our awe of the force of these storms has made it easy to place them in the category of irresistible forces. The ability of the reinforced concrete structure to survive the forces of a tornado has cast aside this notion to a certain extent. However, it is still easy to dismiss the "tornado proofing" of the family dwelling as economically infeasible. Dr. Melaragno's review should give encouragement to restudy the methods of construction in light of

It may not be possible to construct buildings that will survive the center line of the path of intense tornadoes, but it certainly would seem possible to reduce the damage, or control the damage of dwellings at the edge of the path. The Manhattan, Kansas, storm of 1966 and the Garden City, Kansas, storm of 1967 are good examples of types of tornadoes whose damage could be greatly reduced by altering some of our current construction practices.

Texas Tech's 1971 Lubbock Tornado Report

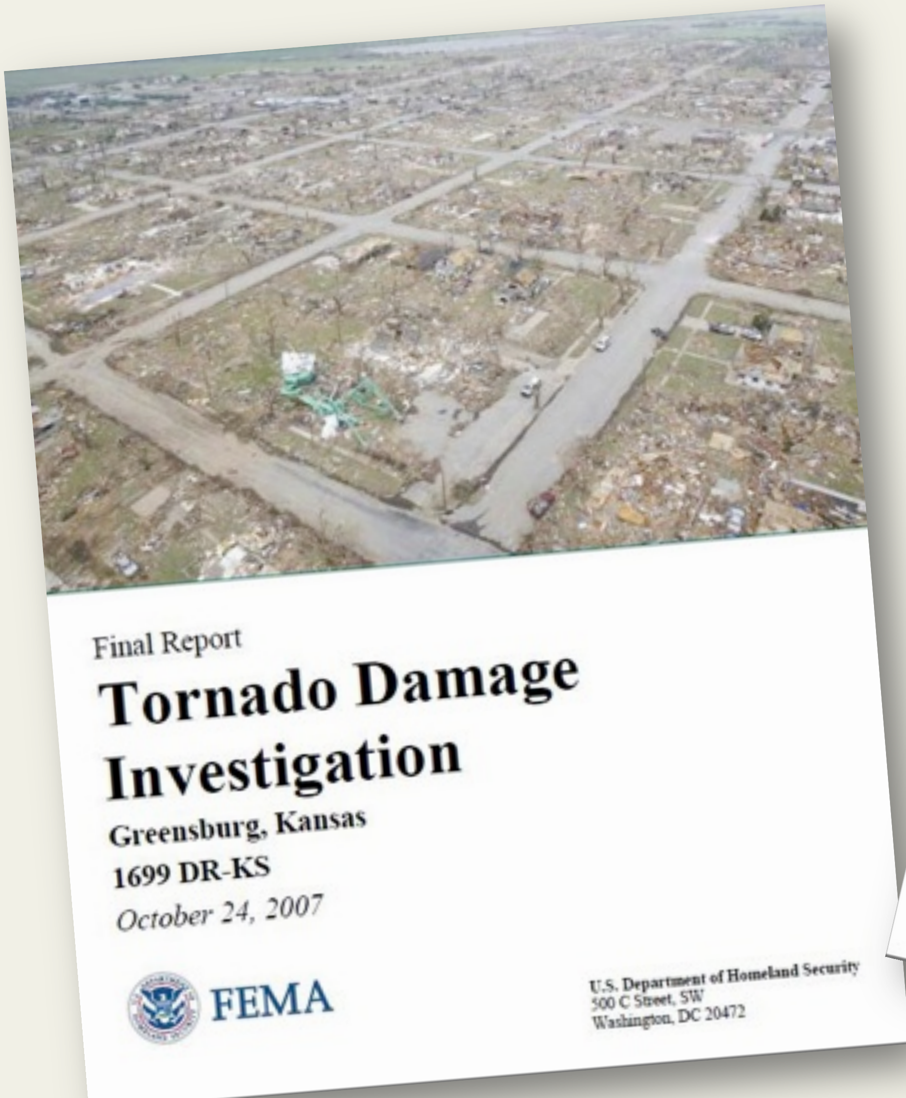
- Highest near-ground wind speeds:
  → 200 mph
- Most damage caused by:
  → 75 to 125 mph winds
- Totally destroyed buildings:
  → failure of weak links led to progressive failures

Construction (material and engineering) – important determinants of bldg. performance

→ RC Bldgs – limited damage → Steel – severe damage → Masonry – severe

→ Multi-family units – roof removals, upper story damaged, interior partitions ok
→ Single-family houses – total destruction, extensive and widespread damage

FEMA Reports (1990 -2007)

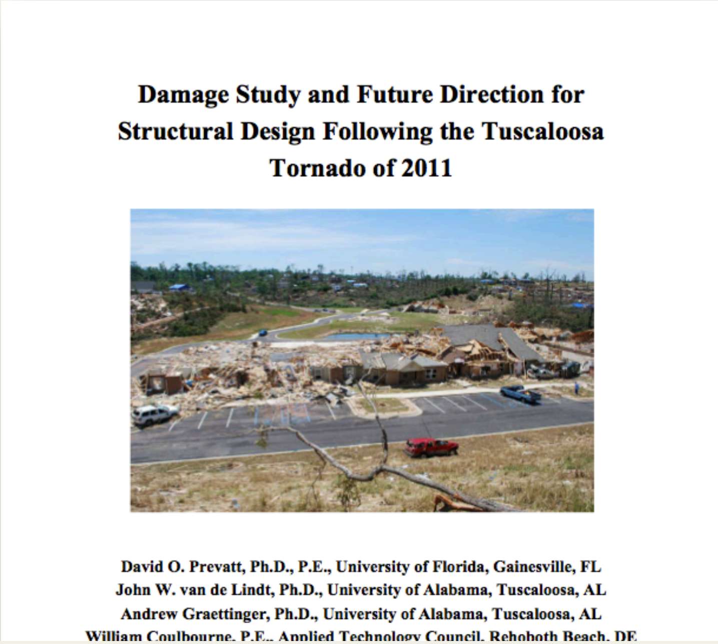


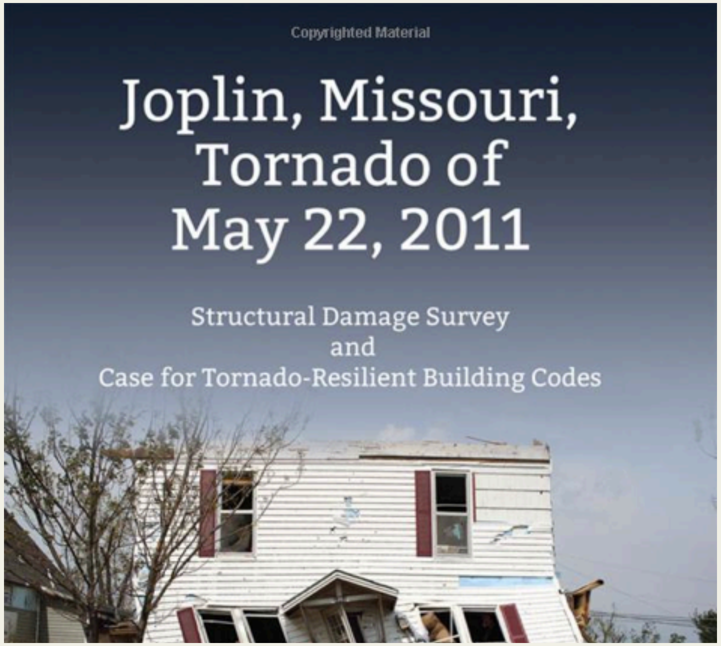
Hidden Consequences

- Loss of family structure / support networks
- Neighborhoods suffer
- Unemployment, housing shortages
- Interrupted education, schools destroyed
- PTSD, stress-related medical issues

Not quantified by FEMA or Engineering Bldg Damage Reports

Response to the 2011 Tornadoes





Structural / Wind Engineers are Re-Mobilized:

→ National Science Foundation – Tuscaloosa report
→ American Association of Civil Engineers – Joplin report
→ NOAA – Weather Ready Nation – addressing social AND physical consequences

→ Several reports by many teams, & peer-reviewed research papers available
→ Tornado Design Load Included in Commentary of ASCE 7-16 Load Standard

Making the Case for Improved Structural Design: Tornado Outbreaks of 2011

David O. Prevatt, Ph.D., M.ASCE;
John W. van de Lindt, Ph.D., M.ASCE;
Edward W. Back, Ph.D., M.ASCE;
Andrew J. Graettinger, Ph.D., M.ASCE;
Shiling Pei, Ph.D., M.ASCE;
William Coulbourne, M.E., M.ASCE;
Rakesh Gupta, Ph.D., M.ASCE;
Darryl James, Ph.D.; and Duzgun Agdas, Ph.D.

ABSTRACT: A total of 1,625 tornadoes occurred in the United States in 2011, resulting in economic losses that exceeded $25 billion. Two tornado outbreaks stand out because they

The year 2011 was one of the deadliest for tornadoes on record in the United States, with 1,625 tornado occurrences

pheric Adm... Center 201... nomic loss... 2011), and... outbreaks a... were respon... damages, an... Forecasting... recent dama... tornadoes o... Tuscaloosa,... struck Jopli... 2011a, c)... wood scien... damage left... perishable d... ticular atten... residential h...

Despite s... both the bui... for over hal... mercial buildings have been designed and built in essentially the same way. This class of structures, representing between 85% and 90% of the current U.S. building stock, are typically site-built, using

wood sheathing (e.g., plywood and/or oriented strand board) nailed onto light-frame wood and, more recently, cold-formed steel framing and covered with as-...

...NOAA 2012]. In less than an hour, the tornadoes destroyed or caused major damage to more than 13,000 residential structures combined, or 12.6% and 30.2% of the housing stock in Tuscaloosa and Joplin,

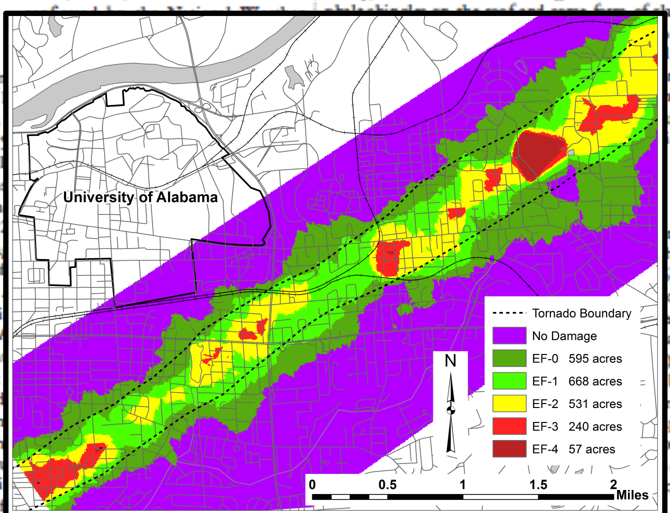
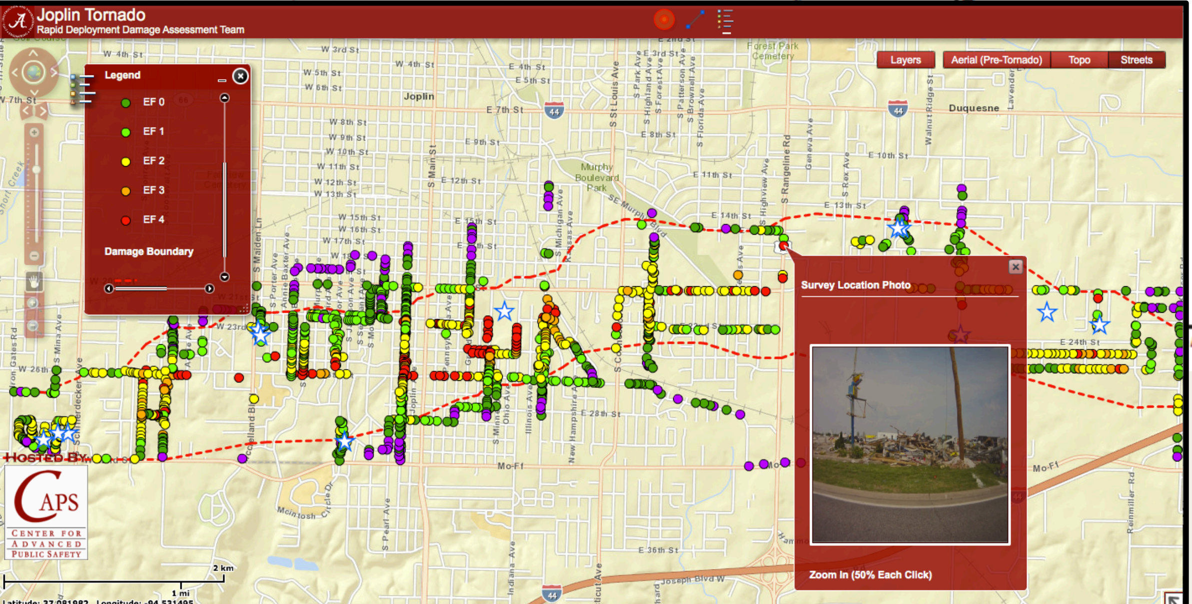


Figure 1. Location map for Tuscaloosa tornado



EF-Rating vs. Actual Damaging Winds

EF level	Wind Speed (mph)	Area on Map (acres)	% by Area
0	65-85	908	22.9%
1	86-109	1179	29.8%
2	110-137	1211	30.6%
3	138-167	494	12.5%
4	168-199	166	4.2%
5	200-234	0	0.0%

83%

Joplin, MO Tornado 22 May 2011

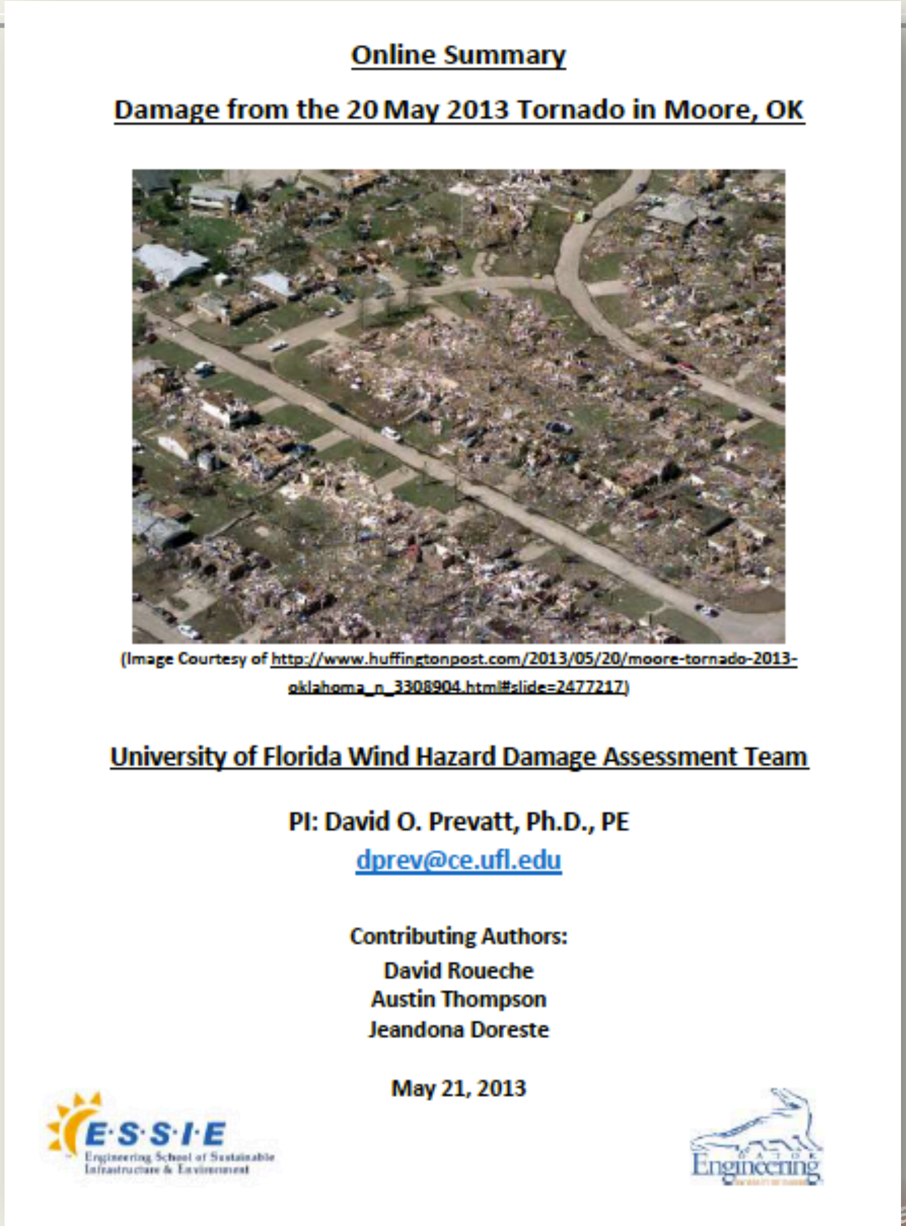
EF2 Level Damage (110-137 mph)

EF4 Level Damage (168-199 mph)

St. John’s Regional Hospital

2013 Moore, OK Tornado

- 3 tornadoes since '99
- But little change to building code
- Same damage to housing
- → Fewer deaths (FEMA shelters)


Online Summary

Damage from the 20 May 2013 Tornado in Moore, OK

(Image Courtesy of http://www.huffingtonpost.com/2013/05/20/moore-tornado-2013-oklahoma_n_3308904.html#slide=2477217)

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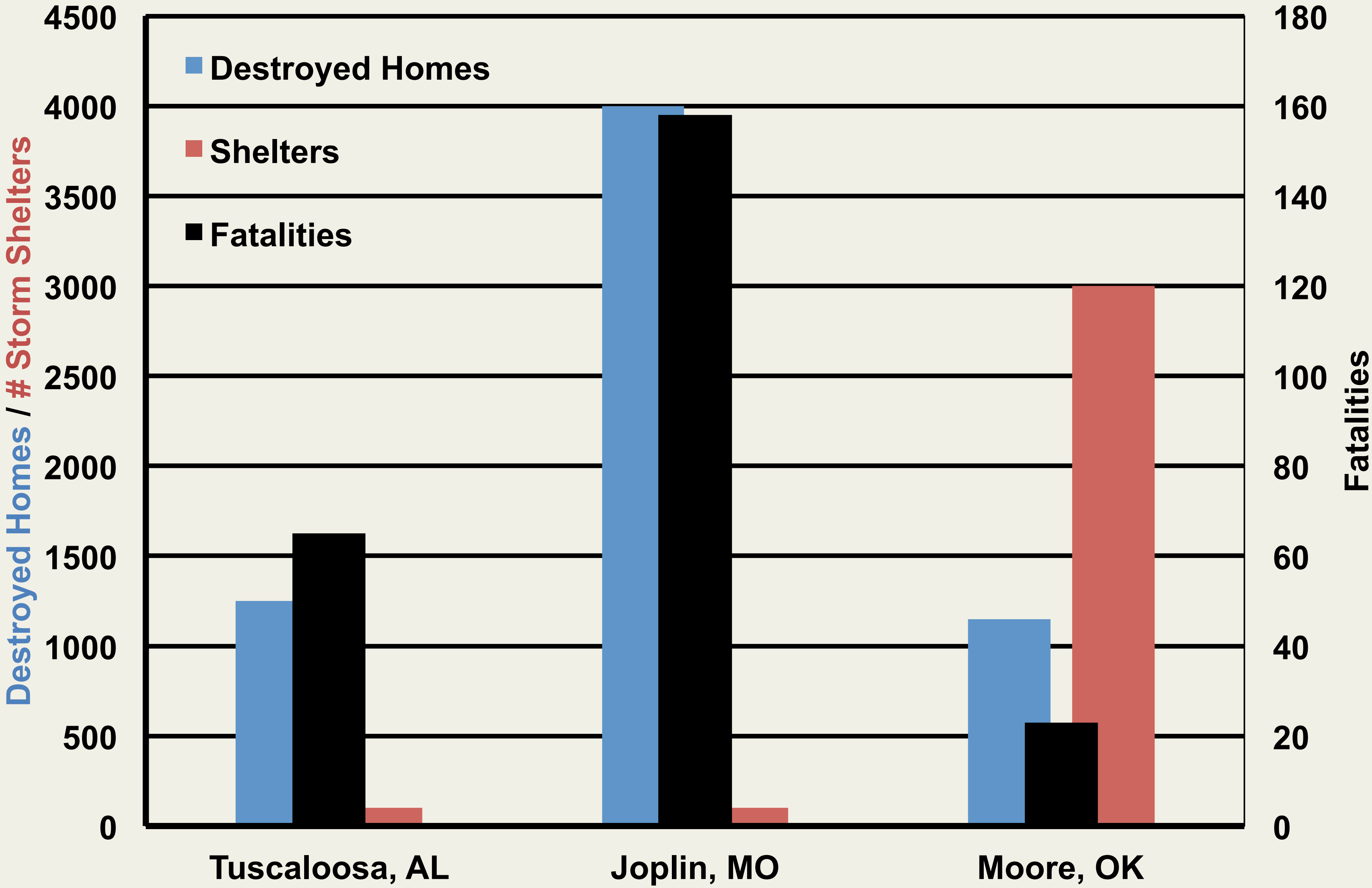
May 21, 2013

2011 & 2013 Tornadoes



Dual-Objective-Based Tornado Design Philosophy

John W. van de Lindt, M.ASCE[1]; Shiling Pei, M.ASCE[2]; Thang Dao, A.M.ASCE[3]; Andrew Graettinger, M.ASCE[4]; David O. Prevatt, M.ASCE[5]; Rakesh Gupta, M.ASCE[6]; and William Coulbourne, M.ASCE[7]

Abstract: Tornadoes represent a unique natural hazard because of the very low probability of occurre[illegible] warning times (on the order of only a few minutes), and the intense and destructive forces imposed on engineered and non[illegible] The very low-probability/very high-consequence nature of a tornado strike makes designing for survival an[illegible] [illegible]pical financial constraints a substantial challenge. On April 27, 2011, an enhanced Fujita (EF) 4 (EF4) to[illegible] [illegible]-km (5.9-mi) long, 0.8-km-wide (1/2-mi-wide) path, through the city of Tuscaloosa, Alabama, and [illegible] 130 km (80 mi). This paper presents the design concept that resulted following a week-long data [illegible] [illegible]roughout the city of Tuscaloosa by the authors. The dual-objective philosophy proposed herein is [illegible] [illegible]ding damage and loss reduction in low-to-moderate tornado wind speeds and building occupant life safety in [illegible] [illegible]-speed events such as EF4 and EF5 tornadoes. The philosophy articulates a design methodology that is the basis upon which [illegible] [illegible]ral engineering was formed—namely, provide life safety and control damage—but the new philosophy is focused at separate tornado intensity levels. **DOI:** 10.1061/(ASCE)ST.1943-541X.0000622.

Life Safety AND Building Performance

CE Database subject headings: Tornadoes; Residential buildings; Natural disasters; Structural design.

Author keywords: Tornado; Residential building; Natural hazard; Design method.

Applying the Philosophy

Methodology Proposed	Enhanced Fujita Scale Winds (3-sec gust)					
	EF0 (65-85)	EF1 (86-110)	EF2 (111-135)	EF3 (136-165)	EF4 (166-200)	EF5 (>200)
Design Objective Damage (D)/Life Safety (L)	D	D	D/LS	D/LS	LS	LS
Philosophy Considered Component (C)/System (S)/Alternative (A)	C	C	C/S	S	S/A	A

Wind speeds that Damage Houses

- Toe-nailed roof-to-wall connection fails – 105 mph
- Suction force exceeds weight of house – 125-135 mph
- Wall studs can be broken (2 x 4 lumber) – 105 mph
- Houses sliding failure (anchors at 6 ft o.c.) – 105 mph

A Tornado-Resilient House?

- Use structural fasteners and connections for hurricanes
  - Vertical Load path – beefier wood members
  - Ring shank nails, metal hurricane straps,
  - More anchor bolts into foundation
  - Continuous structural sheathing on walls
  - Outlaw TOE-NAILED roof-to-wall connections!!
- Utilize potential strength of interior partition walls
  - i.e. use same anchorage and metal tie connection as exterior walls
  - Brace exterior walls using strengthened interior partitions
  - Design roof hold-downs through interior partitions
- Reinforce exterior building corners to hold together

Concluding Thoughts

- Catastrophic damage to housing stock is unacceptable
- Tornado-resilient housing - a feasible and realistic objective
- Better building codes will strengthen the housing sector.

- Involve the community to find multi-faceted solutions
  – (social science, engineering, political, & physical science)
  – Engineering, Engagement and Education – a must!

Thank you for Your Attention!

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Online Link to Surveys

- Moore
  – http://esridev.caps.ua.edu/MooreTornado/MooreTornado.html
- Tuscaloosa
  – http://esridev.caps.ua.edu/tuscaloosa_tornado/
- Joplin
  – http://esridev.caps.ua.edu/JoplinTornado/