Performance-Based Design for Tornadoes

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Context:
Building Codes and Standards

National model building codes, standards, and practices seek to achieve life safety for the hazards considered in design.

Tornado hazards are not currently considered in the design of buildings, except for safety–related structures in nuclear power plants, storm shelters, and safe rooms.

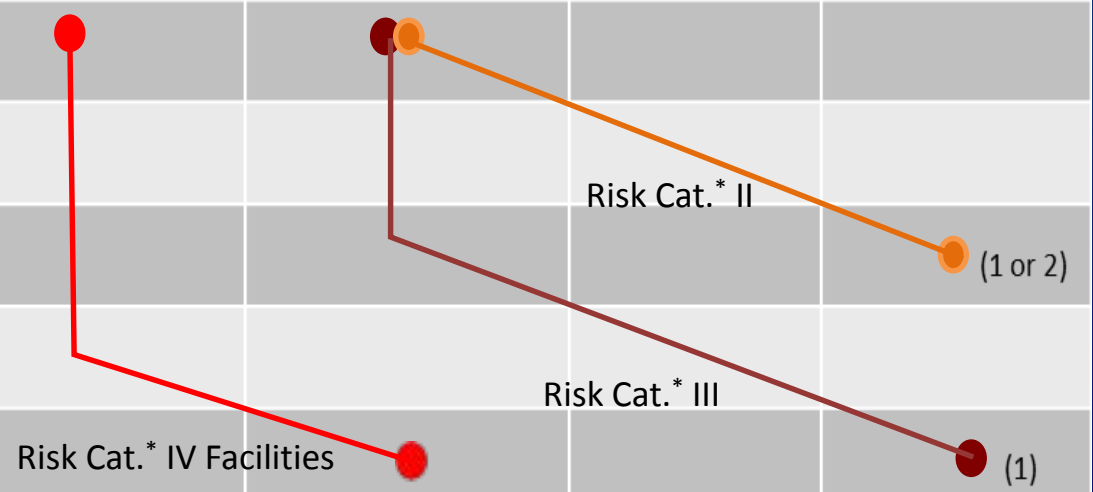
Development of Performance-Based Standard for Tornado-Resistant Design

Recommendation 5 (ASCE): NIST recommends that nationally accepted performance–based standards for the tornado–resistant design of buildings and infrastructure be developed in model codes and adopted in local regulations to ensure the resiliency of communities to tornado hazards. The standards should encompass tornado hazard characterization, performance objectives, and evaluation tools. The standards shall require that critical buildings and infrastructure such as hospitals and emergency operations centers are designed so as to remain operational in the event of a tornado.

- **Target Standard: ASCE 7-22**
  Minimum Design Loads and Associated Criteria for Buildings and Other Structure

Example Tornado Performance Objectives Matrix

Tornado Intensities	Performance Objectives			
	Operational	Repairable Occupancy	Life Safe	Collapse Prevention
EF1 (86-110 mph)				
EF2 (111-135 mph)				
EF3 (136-165 mph)				
EF4 (166-200 mph)				
EF5 (> 200 mph)				



(1) Hardened area, shelter–in–place.
(2) Public shelter.
* Based on ASCE 7–10.

Implementation of Performance-Based Design (PBD)

Continued working with ASCE Technical Committee on PBD for Extreme Winds (ad-hoc)

- Committee is creating a PBD framework for extreme wind hazards, including tornadoes, intended for inclusion in ASCE 7-22.
- Developing performance objectives and building performance levels for different wind hazards and risk categories of buildings
  - hurricanes, tornadoes, other windstorms
  - structural, cladding, and other building systems

ASCE 7-22 Development Cycle

- Call for membership for ASCE 7-22 standards committee closes September 30, 2017
- The Wind Load Subcommittee (WLSC) will be organized differently this cycle, with a small main committee and working groups for each chapter
- NIST to lead the working group that will develop a proposed new chapter on Tornado Loads
- The Ad-Hoc Technical Committee on PBD for Extreme Winds will be absorbed into the WLSC
- Committee meetings to begin late in 2017/early 2018

Implementation of Performance-Based Design (cont'd)

Additional requirements to implement PBD for tornadoes

- New tornado hazard maps (R3)
- New tornado wind load design methods (R6)
  - variation of wind speed with height and terrain
  - pressure coefficients
  - atmospheric pressure change (APC)
  - missiles

R&D Project on Tornado Loading

New award under NIST Disaster Resilience Research Grants Program[1], announced August 2017, will inform development of wind load design methods.

Development of Tornado Design Criteria for Buildings and Shelters Subject to Tornado Induced Loads (ARA, Inc.)

- Experimental and modeling research to develop tornado loading criteria
- Experimental work uses UWO's ABL wind tunnel to study effect of tornado vertical wind and Tornado Simulator to study effect of tornado size relative to building size and APC on internal wind pressures.
- Modeling work aims to capture key insights on tornado-induced pressures (including APC) and to develop (1) fragilities that relate tornado wind speed to the probability of damage and (2) recommended loads for tornado-resistant design.

[1] https://www.nist.gov/news-events/news/2017/08/nist-funds-12-projects-make-communities-more-resilient-disasters

Tornado Hazard Mapping

Recommendation 3 (NIST): NIST recommends that tornado hazard maps for use in the engineering design of buildings and infrastructure be developed considering spatially based estimates of the tornado hazard instead of point–based estimates.

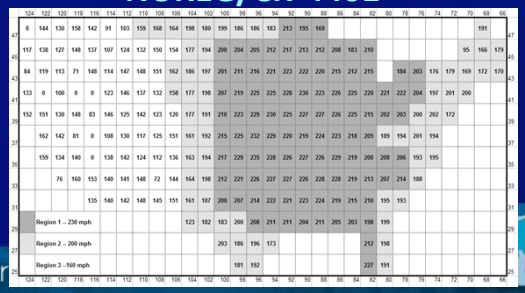
- Existing tornado hazard maps do not account for biases and increased risk of strike on large spatial systems
- Contracted with ARA to develop *Tornado Hazard Maps for Building Design.* Presently 3 years into a four+ year effort
- Significant progress to date in:
  1. Tornado climatology – including quantification of the population bias
  2. Tornado regionalization
  3. Quantification of EF scale damage to wind speed relationship

FEMA 361

ANSI/ANS 2.3 (2011)
for Safety-Related Structures and Components of Nuclear Power Plants

*3-second gust at 33 ft

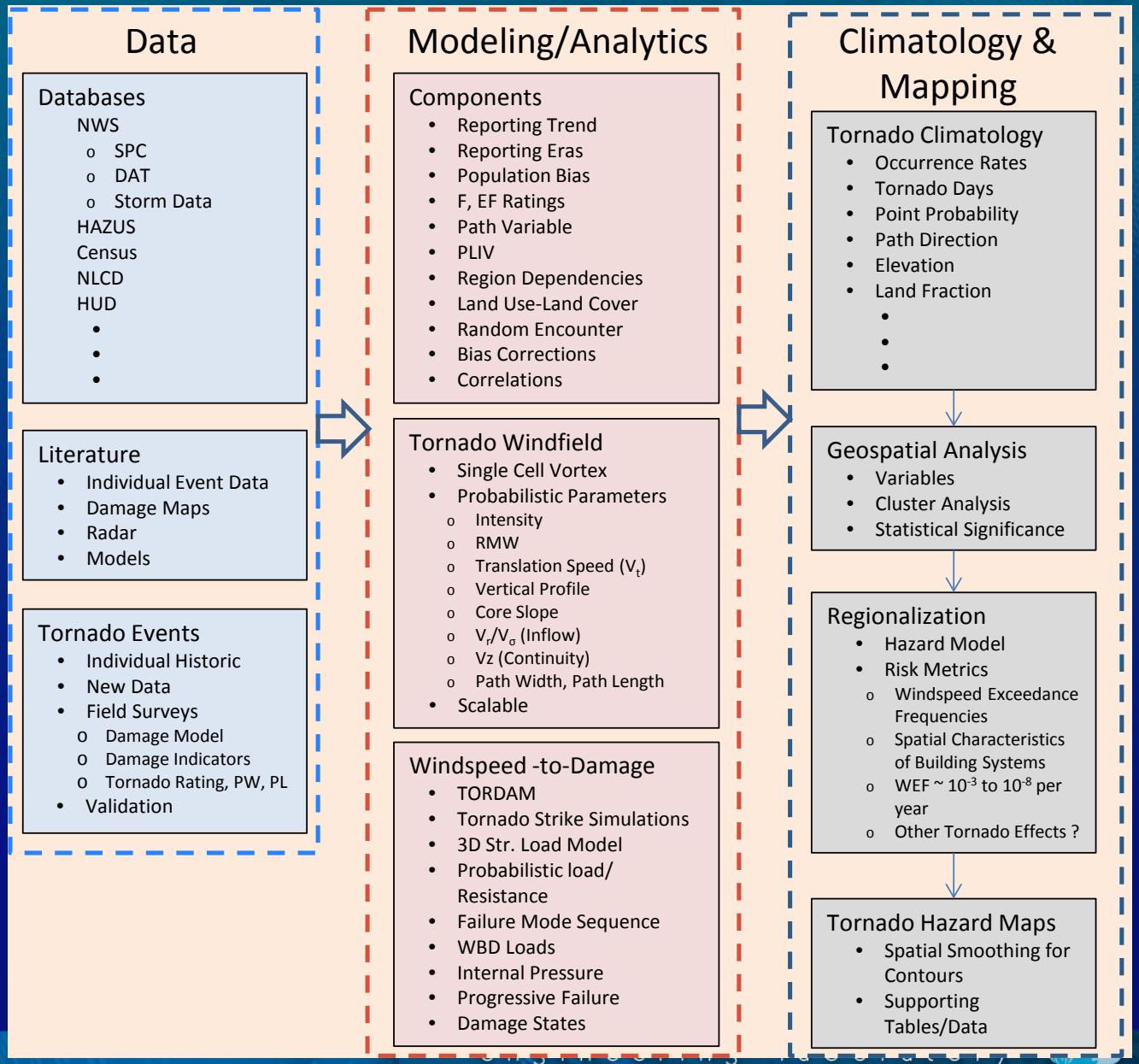
NUREG/CR-4461



Tornado Map Development Process

Approach

1. Build on existing modeling and analysis tools
2. Probabilistic modeling, bias corrections
3. Develop engineering-damage-to-windspeed probabilistic models
4. Develop integrated tornado climatological model
5. Develop regional variations and iterate
5. Finalize PBD metrics and building/system spatial parameters
6. Produce regional tornado windspeed hazard curves and associated metrics
7. Develop tornado spatial variations/ smoothing for maps



Tornado Map Progress Summary (1/3)

- Produced an augmented tornado database for the years 1950-2016, including cleansed and augmented data:
  - Cleansing of errors, discrepancies, zero values, and missing values
  - Source field analysis
  - Path width analysis by era and path width correction based on tornado aspect ratio
- Produced an initial set of tornado regions in the US using an advance cluster analysis algorithm that previously developed for nuclear power plant site tornado hazard analysis.
- Developed data models of intensity, path length, path width, correlation of path width to length, and direction for each of these regions.

Tornado Map Progress Summary (2/3)

- Developed population bias models for two census periods (2000 and 2010) that encompass the years 1995-2016. These models show significant amount of under-reporting for most parts of the US.
- Created probabilistic models for the Enhanced Fujita (EF) Scale Degree of Damage (DOD) system and the relationship of DOD to wind speed and EF-Scale determination.
- Developed probability distributions of DODs and wind speeds given DOD for 18 house types.
- Produced the first-ever engineering based EF-Scale wind speed distributions, $P(V \mid EFi)$.

Tornado Map Progress Summary (3/3)

- Performed 3 tornado damage surveys, including accompanying the NWS survey team and observing their processes.
  - EF1 Luther, OK Tornado (April 26, 2016).
  - EF1 Ottawa, IL Tornado (June 22, 2016)
  - EF4 Perryville, MO Tornado (February 28, 2017)
- Completed the random encounter modeling for an infinite grid of targets. This work will be used to characterize the probabilities of tornadoes occurring but not hitting DIs and also to model the effect of EF-Scale limited DIs, such as barns, where the maximum rating is less than EF5, no matter how strong the tornado might have been.

Tornado Maps – Next Steps (1/2)

- NIST is in the process of awarding the task order for the last phase of map development
- Key objectives towards completion of the maps
  - Finalization of augmented tornado database and associated analysis, including population bias
  - Tornado windfield modeling and probabilistic analysis of EF scale windspeeds
  - Development of draft tornado wind speed risk map for ASCE 7 and for ICC 500
  - Stakeholders Workshop in 2018 to present draft maps and obtain feedback
  - Work closely with ASCE 7 and ICC 500 committees through the standards development and balloting processes on development and approval of final maps

Tornado Maps – Next Steps (2/2)

- The Nuclear Regulatory Commission (NRC) will be co-funding explicit consideration and propagation of epistemic (modeling) uncertainty
- Documentation of the map development process through reports and journal and conference papers.
- Publication of key data underlying the maps, such as the augmented tornado database