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Latest Developments in Tornado Hazard Characterization and Tornado Loads on Buildings/Structures

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This presentation will provide an overview of current developments in characterization of tornado hazards, as well as design of buildings and other structures to resist these hazards.

The first-ever engineering-derived tornado wind speed maps have recently been produced for the contiguous United States. Tornado databases (for the years of 1950-2016) and physiographic data were analyzed to identify large-scale spatial patterns with similar tornado characteristics, using multi-variate statistical analysis of 11 tornado and physiographic variables. From these patterns, nine broad U.S. regions with distinct tornado climatologies were developed. Regional and national data were analyzed to produce probabilistic models for: population bias; EF-Scale distribution; tornado path length, width, direction, and translational speed; radius of maximum winds; tornado path length intensity variation; variable path widths within a tornado; mean to maximum path width ratios; and maximum damage widths relative to local path width. A probabilistic load and resistance modeling framework was used to develop engineering-derived wind speeds from the Enhanced Fujita Scale (EF-Scale) tornado intensity rating system. These data were used to support development of a probabilistic tornado wind field model. Monte Carlo methods were then used to simulate tornadoes, produce damage swaths, score wind speed exceedances numerically over a wind range of wind speeds, and develop regional tornado hazard curves. Since tornadoes often have modest path widths relative to the size of the structure, tornado wind speed risk depends on structure size. Therefore, the tornado hazard curves were developed as a function of structure size.

Tornado hazard maps were then produced for return periods of 300, 700, 1,700, and 3,000 years, following ASCE 7 Risk Category return periods, as well as 10,000, 100,000, 1,000,000, and 10,000,000 years. These eight return periods span the range of design needs for conventional buildings and structures, critical and essential facilities, and nuclear power plants.

Maps were produced for eight structure sizes at each return period, ranging from point targets to 4 million ft^2. The maps were developed through probabilistic models that are "best estimates" rather than "conservatively based". Epistemic (modeling) uncertainties were considered in the map development process. As a result, the maps are also intended for applicability to the nuclear power industry in the US, where both aleatory (randomness) and epistemic uncertainties are required in the risk analysis of nuclear power plants.

These new probabilistic tornado hazard maps have been incorporated into a tornado load methodology proposed for inclusion in the ASCE 7-22 Standard: *Minimum Design Loads and Associated Criteria for Buildings and other Structures.* The loading methodology breaks new ground in several areas, including: using radar measurements of tornadoes to define the vertical velocity profile of horizontal winds; developing a pressure coefficient adjustment factor to account for differences in building aerodynamics caused by the vertical component of the wind near the core of the tornado compared to horizontal winds in other storms; and a new internal pressure coefficient that incorporates the effects of both external wind pressures and atmospheric pressure change.

Laying the groundwork for future improvements to tornado hazard mapping is a forthcoming ASCE/AMS *Standard on Wind Speed Estimation in Tornadoes and Other Windstorms*. This new standard will include major improvements to the Enhanced Fujita Scale method for tornado wind speed estimation, as well as improvements to several other methods.