Wind Engineering Research Group
Northeastern University

Performance-based Tornado Engineering (PBTE) of a Vertical Structure via Artificial Neural Network (ANN) Surrogate Modeling

Viet Le, Ph.D. Candidate; Luca Caracoglia, Associate Professor
Department of Civil and Environmental Engineering Northeastern University, Boston, MA

MathWorks Day
February 21, 2020

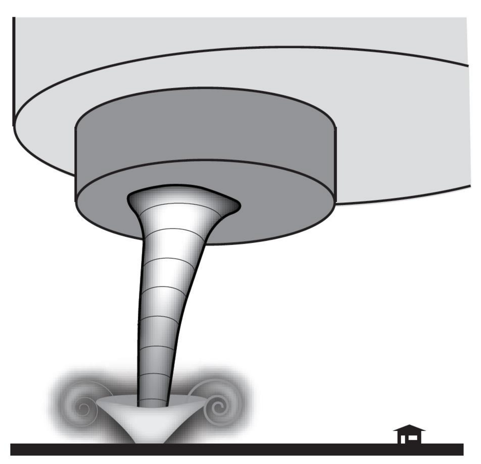
ABSTRACT

The thrust of the research is to propose the use of artificial neural networks (ANNs) as surrogate models in a performance-based tornado engineering framework to rapidly approximate fragility functions and characterize damages of vertical structures. These ANNs are trained with a subset of numerically generated structural responses from simulated tornadoes. By employing an ensemble of these systems, the stochastic properties of the calculated probabilities of failure can be extracted and then used to evaluate relative life-cycle repair costs. Successful application of this approach can ultimately provide vital knowledge related to the structural performance of the built environment impacted by tornado wind loads from both engineering (hazard and fragility curves) and economic perspectives (life-cycle costs).

INTRODUCTION

Tornadoes

- Present challenging **structural engineering problems** due to **intense wind loading**



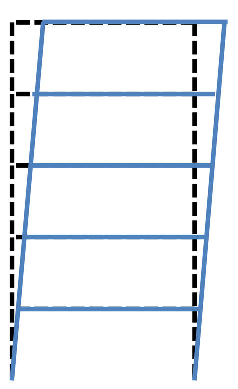

(Source: Amateur photograph from Time magazine)

Performance-based Tornado Engineering (PBTE)

- Ensure a structure satisfies **performance objectives**

For example:

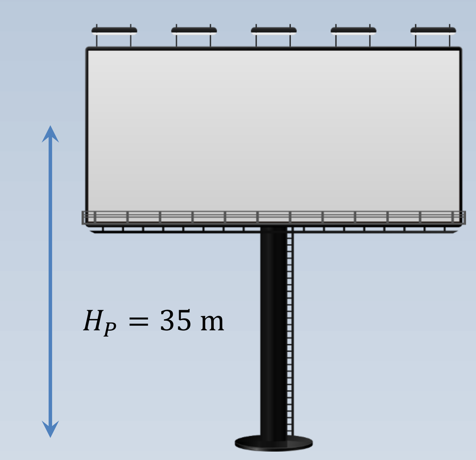
- Permanent lateral drift
- Unsightly (out of plumb) appearances
- Overturning base moment (collapse prevention)




ACKNOWLEDGEMENTS

- MathWorks Inc. Micro-grant, awarded by Prof. Miriam Leeser, ECE Department
- Dr. Thai-Hoa Le (SOH Wind Engineering, Williston VT)

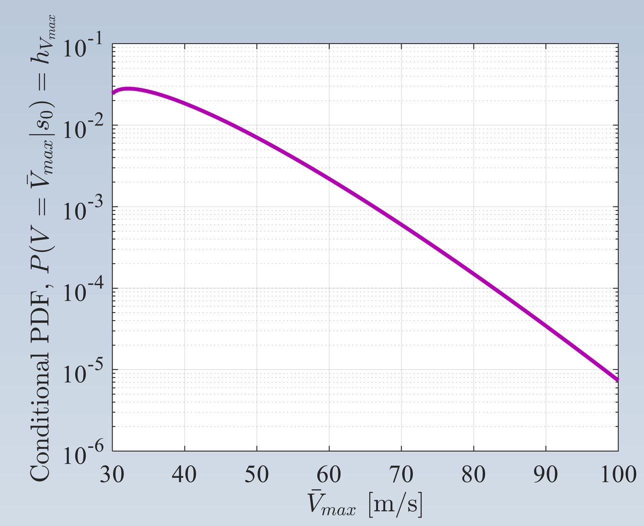
Identify Structure at Risk → **Hazard Analysis** → **Structural & Damage Analysis** → **Loss Analysis** → **Decision Making**



Vertical structure

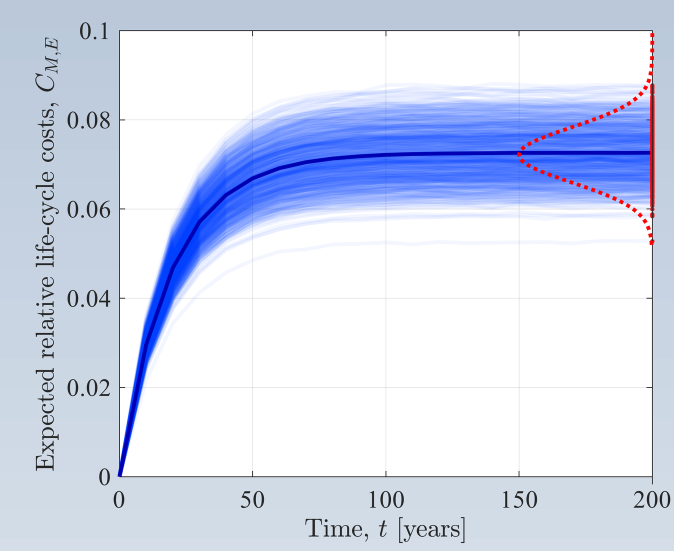
- Monopole tower (plate-like structure)

IM's = $\bar{V}_{max}$, R $\qquad h(IM)$



- **Intensity measures** of the windstorm
- Extracted from publicly available databases (NOAA/NWS Storm Prediction Center - SPC)

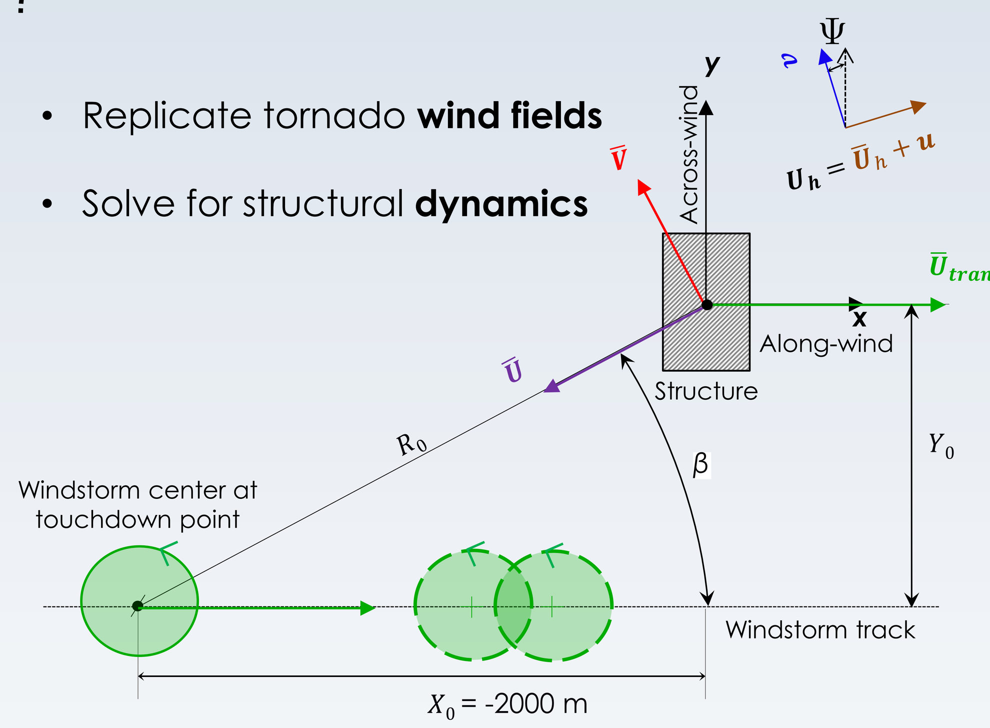
$$\mathbb{E}\left[\sum_{i=1}^{N(t)}\sum_{j=1}^{k}\epsilon_j e^{-\lambda t_i}P_j\right]$$



- Translate risk into economic terms through **life-cycle cost assessment** *($C_{M,E}$ normalized cost with respect to construction cost)*

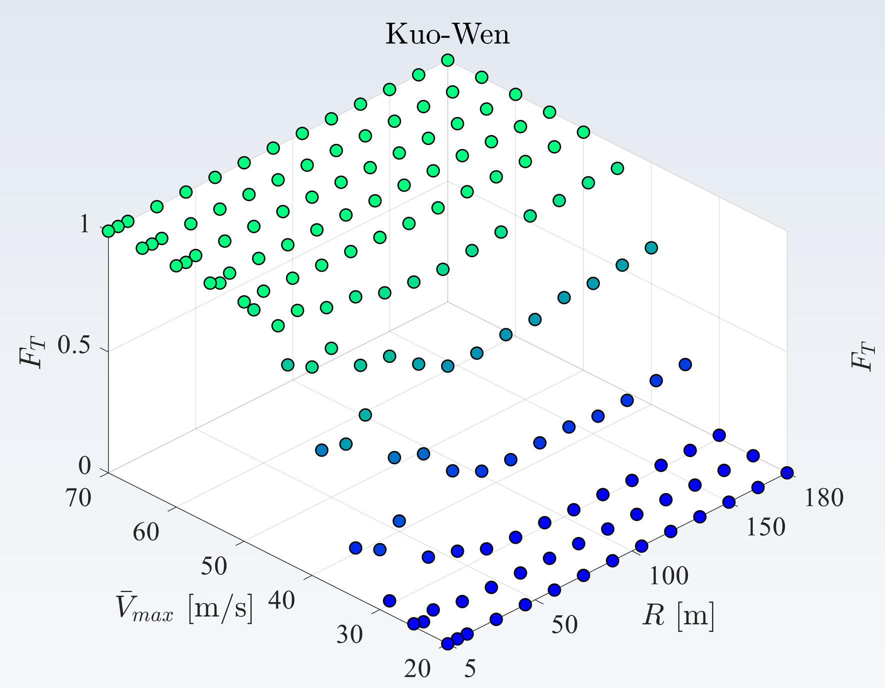
- Rapid, **risk-informed** decisions
- Promote **sustainable** and **economic** design

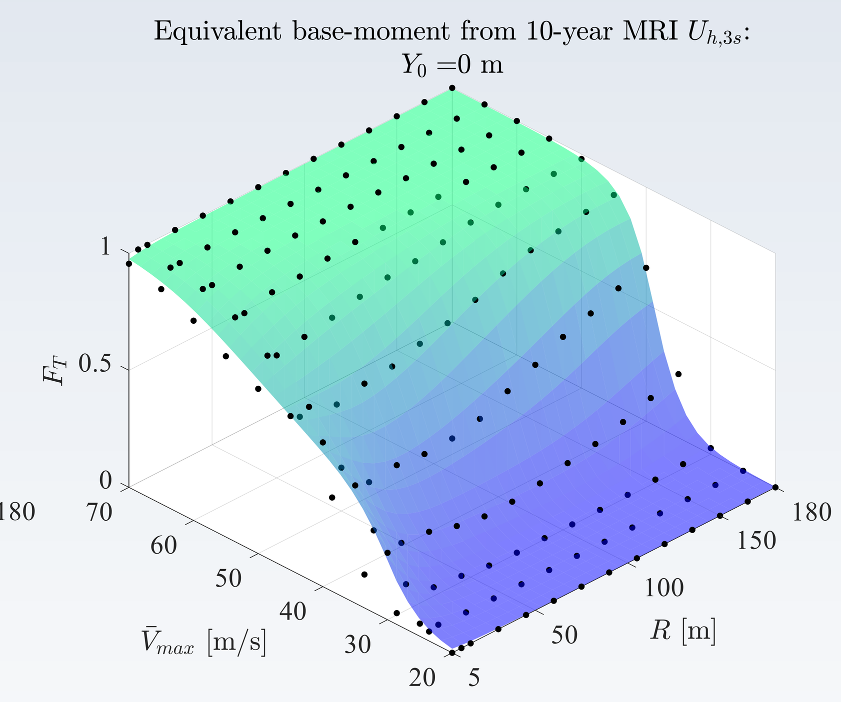
- Replicate tornado **wind fields**
- Solve for structural **dynamics**



Plan view schematic of fluid-structure system

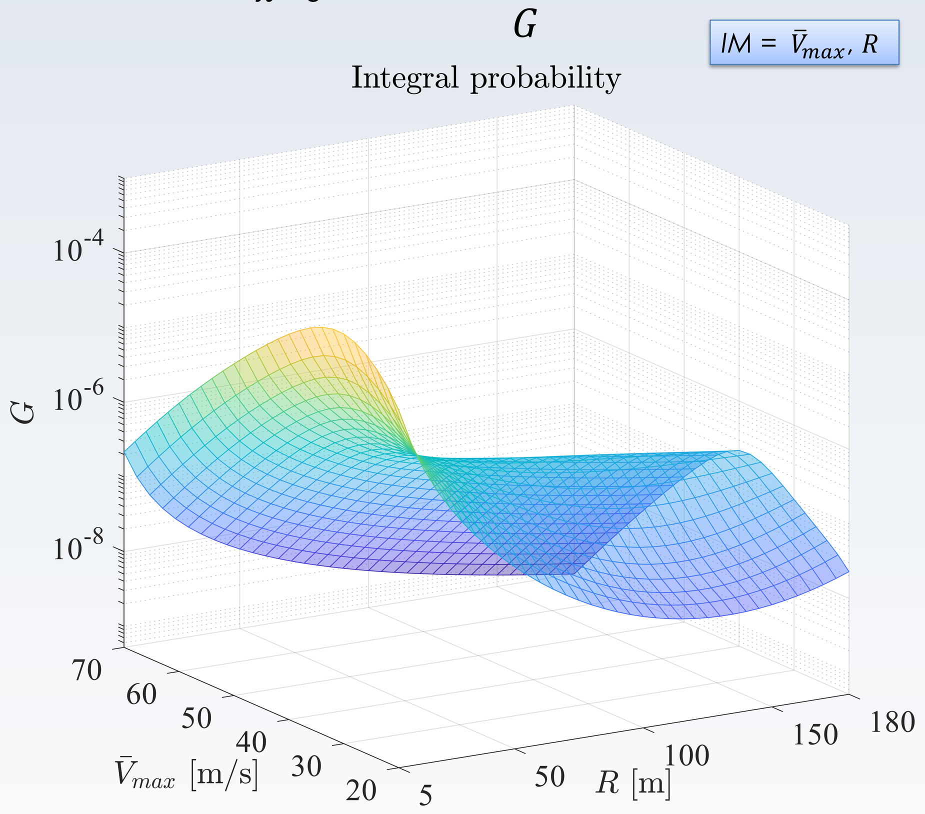
$$F_T(IM) = \mathrm{P}[q_{r,max} > T \mid IM]$$

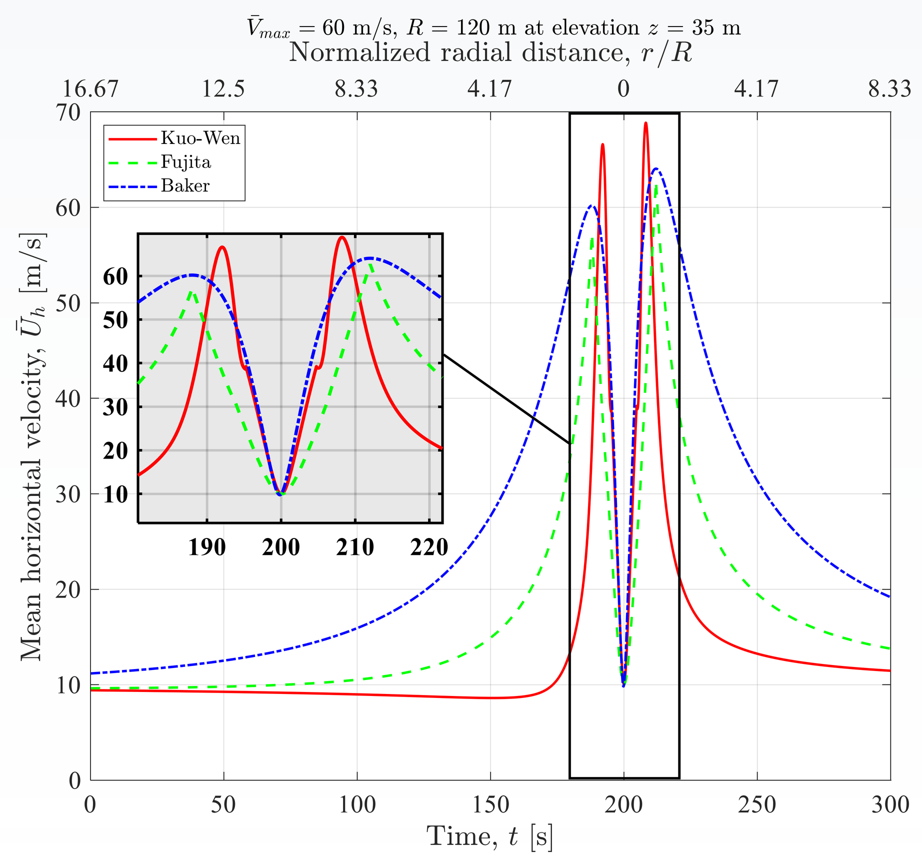




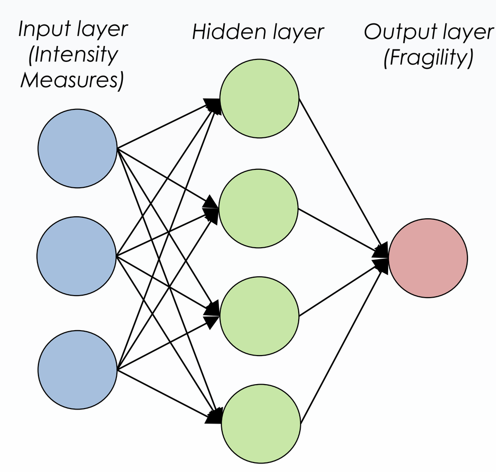
$$P_f = \underbrace{\int_{x=0}^{x=\infty} F_T(IM)h(IM)\mathrm{d}IM}_{G}$$

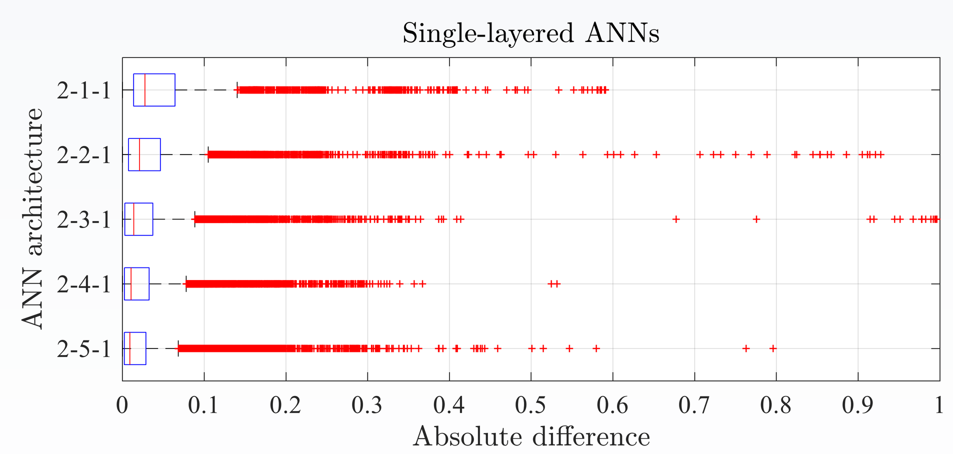
$IM = \bar{V}_{max}, R$



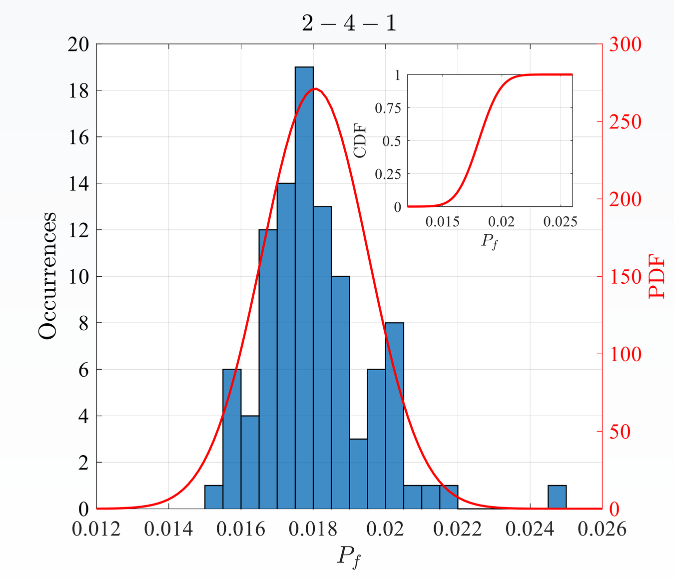


Artificial-Intelligence-based surrogate model





- Fragility points (F_T) approximated with **Monte Carlo** simulations
- **Artificial neural networks** serve as **surrogate models** for fragility (F_T)
- Single layer with four hidden neurons is most accurate
- Highly accurate interpolation of fragilities



- Incorporate together the **hazard** and **structural** information to obtain failure probability P_f
- Stochastic evaluation of P_f enables quantification of modeling uncertainty