Performance-based Engineering Framework for Vertical Structures Subjected to Non-stationary Wind Loads

Viet Le[(1)], Luca Caracoglia[(2)]

(1) PhD Candidate, (2) Associate Professor

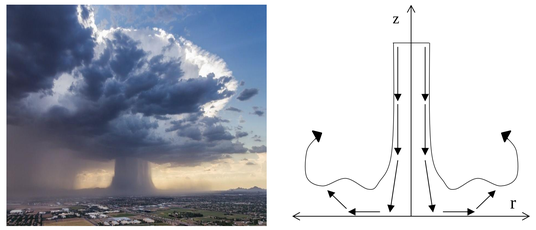
Department of Civil & Environmental Engineering, Northeastern University, Boston, MA 02115

Abstract

- Non-stationary wind storms such as thunderstorm downbursts and tornadoes present challenging structural engineering problems due to their intense wind loading capabilities
- Performance-based engineering (PBE) methods enable flexibility in engineering design while maintaining cost-effectiveness, satisfying performance objectives, and ensuring structural safety for occupants and users.
- However, PBE in wind engineering has primarily focused on synoptic winds using frequency domain analytical methods, that are inadequate for complex non-stationary wind events.
- The objective of the research is to develop a framework that applies the PBE methodology to vertical structures subjected to loading from non-stationary wind phenomena

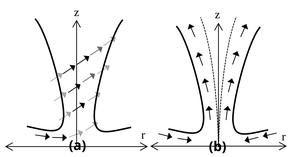
Introduction

Thunderstorm Downburst



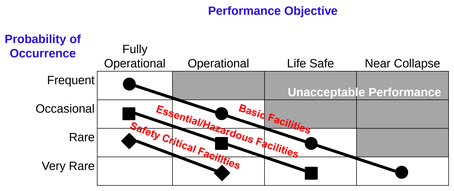
Photograph of thunderstorm downburst (source: google.com) and illustration of its cross-section. Wind flow pushes out radially after impingement.

Tornado



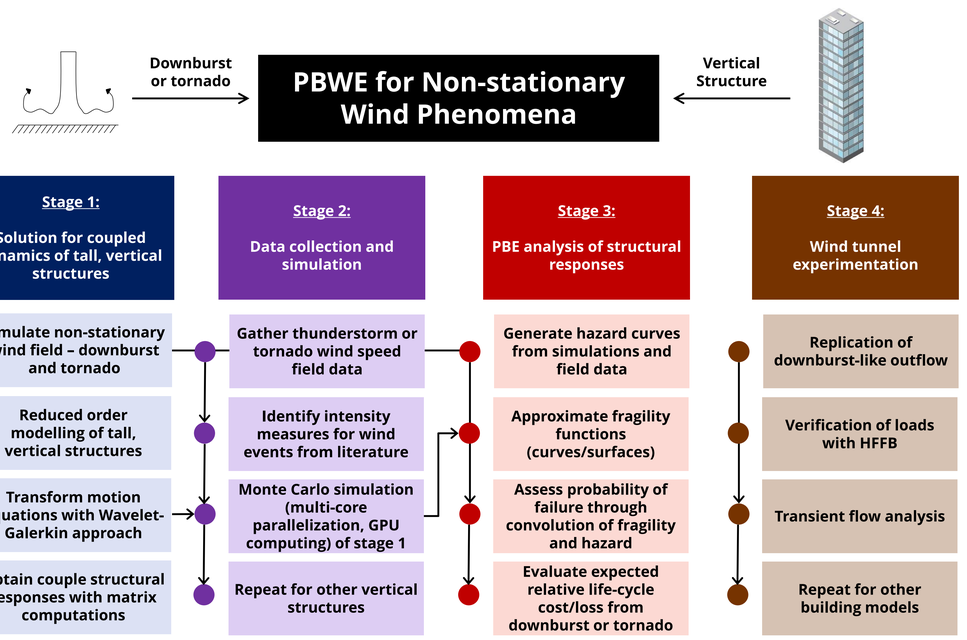
Photograph of tornado (source: google.com) and illustration of (a) frontal view and (b) cross-section view.

Performance-based Engineering

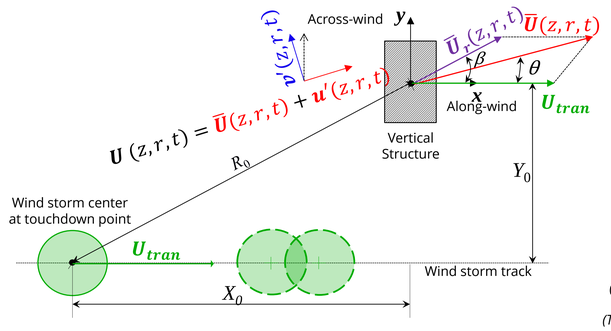


One World Trade Center (source: google.com) and SEAOC Vision 2000 performance objectives for seismic design [1].

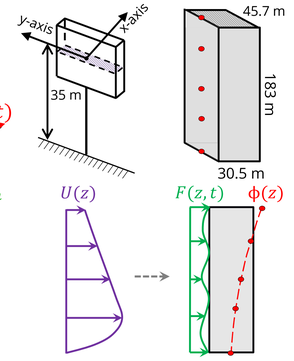
Methodological Framework



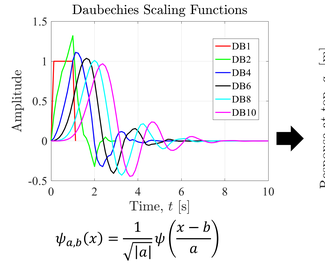
Numerical Simulation Procedure



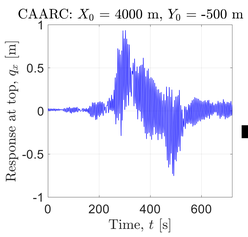
Schematic showing the placement of the structure with respect to the wind storm's path of travel



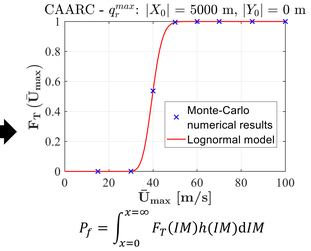
(Top-left) Schematic of reduced-order model of tall building
(Top-right) Schematic of point-like plate structure
(Bottom) Downburst vertical wind profile $U(z)$ and projected forces on tall building



General form of wavelet function and examples of Daubechies family used for WG approach



Example of displacement response output



Example fragility curve for CAARC building with respect to maximum mean wind velocity

Performance-based Engineering Analysis Results

Engineering Demand Parameter (EDP)

$$q^{max} = \max(q)$$

Limit States (LS)

$$T_C = H_C \times \frac{1}{400}$$

$$T_P = H_P \times \frac{3}{100}$$

Complementary Cumulative Distribution Function (CCDF)

$$F_T(IM) = P[q^{max} > T_i | IM]$$

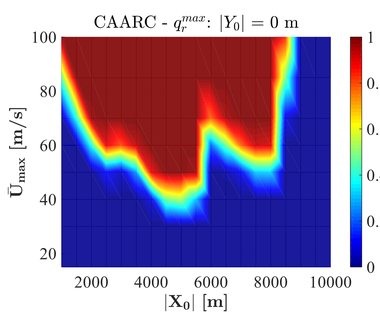
Probability of Failure

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

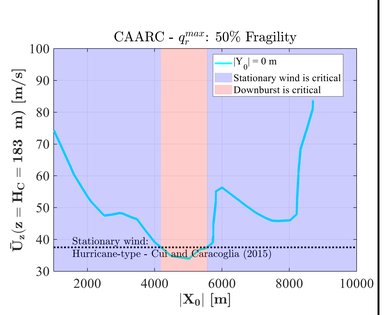
Life-cycle cost analysis

$$E\left[\frac{C(t) - C_0}{C_0}\right] = E\left[\sum_{i=1}^{N(t)}\sum_{j=1}^{k} C_j e^{-\lambda t_i} P_{f,j}\right]$$

Downburst Results:

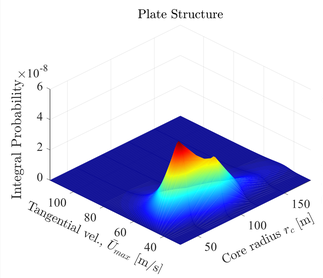


Example fragility surface for tall building subjected to downburst wind loads

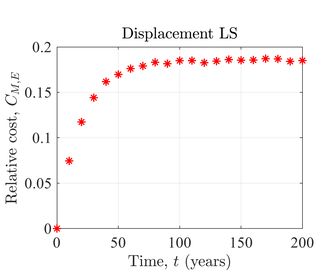


Fragility surface cut to compare fragility results with those from stationary winds

Tornado Results:



Integral probability surface used to compute probability of failure



Expected relative life-cycle cost of plate structure subjected to tornado wind loads

Research Findings

- The Wavelet-Galerkin approach greatly expedites numerical simulations of non-stationary dynamics
- Monte Carlo sampling of engineering demand parameters in the proposed framework can enable performance-based engineering analysis of vertical structures under non-stationary wind loads
- Thunderstorm downburst and tornado wind speeds can exceed those specified by current standards which are not conservative enough from a design standpoint

References

Add your information, graphs and images to this section.

Acknowledgements

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Dr. Thai-Hoa Le (SOH Engineering, Burlington VT, USA), for code development of Wavelet-Galerkin approach.