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Investigations on the Structural Performance of Building Structures Subjected to Non-Stationary Thunderstorm Wind Loads by Wavelet-Galerkin Numerical Methods

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1. ABSTRACT

This study describes implementation of the Wavelet-Galerkin simulation approach for performance-based analysis of structures subjected to thunderstorm downburst wind loads.

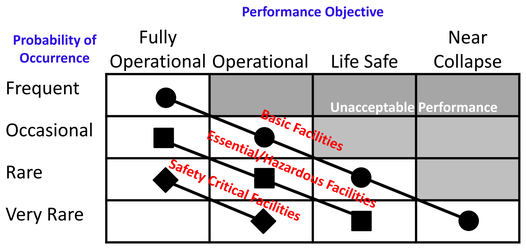
Exploitation of this novel approach is relevant for stochastic simulation of wind loads, structural response, and requiring large simulations in a Monte-Carlo setting.

2. INTRODUCTION

a) Thunderstorm Downburst

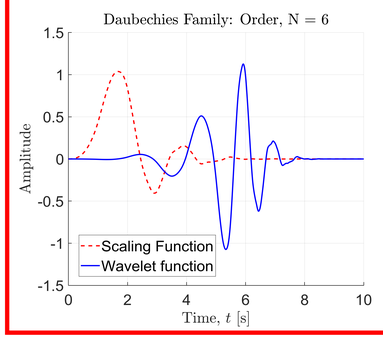
Examples of thunderstorm downbursts (captured by photography and artist's rendition)
(Courtesy: Chopperguy Aerial Productions and Wikipedia)

b) Performance-Based Engineering (PBE)



SEAOC Vision 2000 performance objectives for seismic design – reproduced from [1]

c) Wavelet-Galerkin (WG) Approach [2,3]

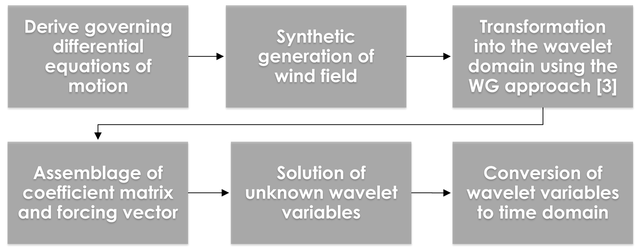


$$\ddot{\eta} = \mathbf{\Omega}^{0,2}\boldsymbol{\eta}_{\{k\}}$$
$$\dot{\eta} = \mathbf{\Omega}^{0,1}\boldsymbol{\eta}_{\{k\}}$$
$$\eta = \mathbf{\Omega}^{0,0}\boldsymbol{\eta}_{\{k\}}$$

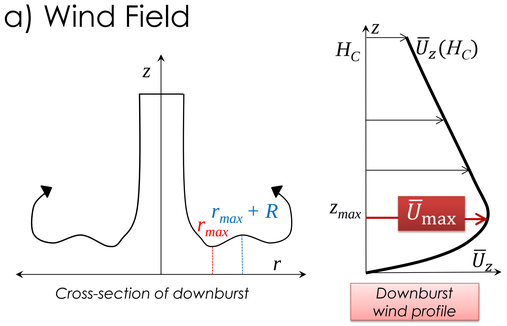
(Above) Connection coefficients [2] to replace derivatives of differential equations

(Left) Daubechies scaling and wavelet functions of order N = 6

3. DYNAMIC SIMULATION



a) Wind Field



Cross-section of downburst

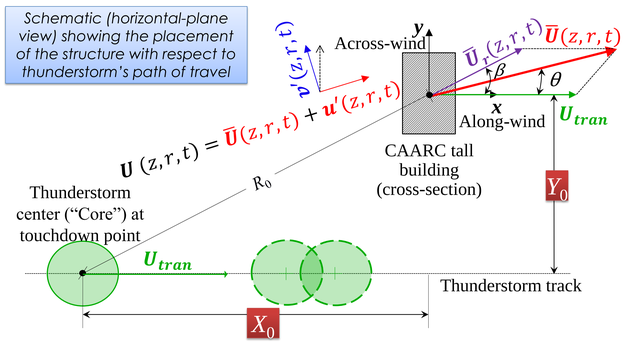
Downburst wind profile

CAARC tall building model

"CAARC" = Commonwealth Advisory Aeronautical Research Council

b) Structural Response

Schematic (horizontal-plane view) showing the placement of the structure with respect to thunderstorm's path of travel

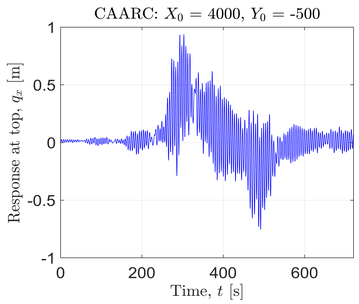


Differential equations of motion (generalized 2DOF)

$$\ddot{\varepsilon}_x + (R_x)\dot{\varepsilon}_x + (S_x)\dot{\varepsilon}_y + (\omega_{0,x}^2)\varepsilon_x = F_x$$
$$\ddot{\varepsilon}_y + (R_y)\dot{\varepsilon}_y + (S_y)\dot{\varepsilon}_x + (\omega_{0,y}^2)\varepsilon_y = F_y$$

WG approach (matrix notation)

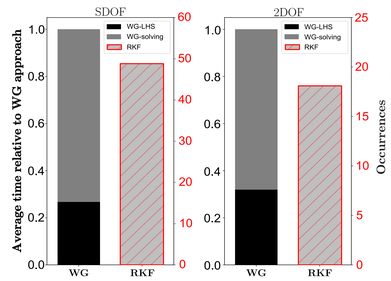
$$[\mathbf{A_{11}}]\boldsymbol{\eta}_{\mathbf{x}\{k\}} + [\mathbf{A_{12}}]\boldsymbol{\eta}_{\mathbf{y}\{k\}} = \{\mathbf{F_x}\}$$
$$[\mathbf{A_{12}}]\boldsymbol{\eta}_{\mathbf{x}\{k\}} + [\mathbf{A_{22}}]\boldsymbol{\eta}_{\mathbf{y}\{k\}} = \{\mathbf{F_y}\}$$



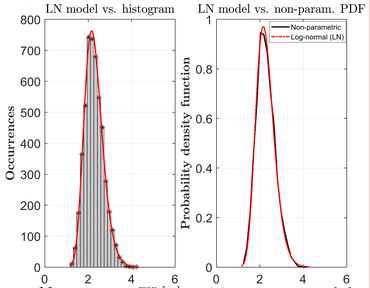
Example of structural response (top-floor horizontal displacement)

4. UNCERTAINTY PROPAGATION

- Wind load and system uncertainty is replicated by Monte-Carlo method.
- Turbulence and force coefficients are randomized.
- Process is repeated for various values of intensity measures.
- Results are compared with Runge-Kutta-Fehlberg (RKF) algorithm.
- Relevant savings in terms of computing time are found



Comparison of relative computation time for simulations between WG and RKF algorithms



Log-normal probability density function(PDF) fitting for the maximum structural response

5. STRUCTURAL FRAGILITY ANALYSIS [4]

Engineering Demand Parameter (EDP)

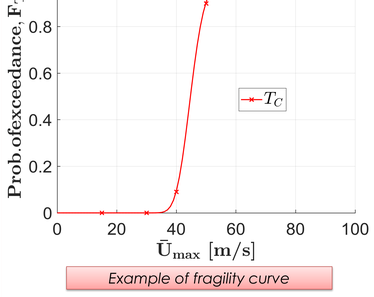
$$q^{max} = \max(q)$$

Limit State

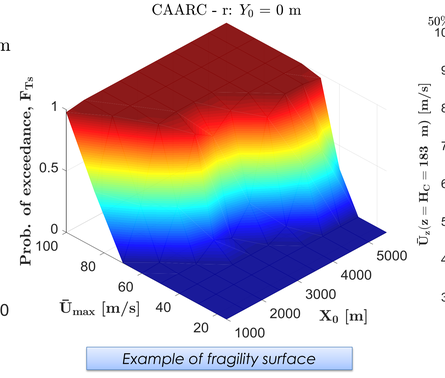
$$T_C = H_C \times \frac{1}{400}$$

Complementary Cumulative Distribution Function (CCDF)

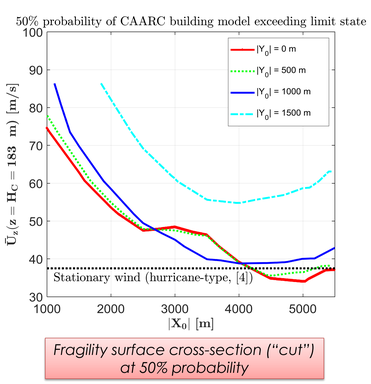
$$F_T(\bar{U}_{max}) = P[q^{max} > T_C|\bar{U}_{max}]$$
$$F_{Ts}(\bar{U}_{max}, |X_0|) = P[q^{max} > T_C|\bar{U}_{Vmax} \wedge |X_0|]$$



Example of fragility curve



Example of fragility surface



Fragility surface cross-section ("cut") at 50% probability

6. CONCLUSIONS AND OUTLOOK

- WG approach is optimal for Monte-Carlo simulation of structural response under non-stationary downburst wind loads
- Fragility curves and surfaces, using maximum mean wind speed of the downburst as an intensity measure, illustrate system's likelihoods for exceeding structural limit states
- Research demonstrates that thunderstorm-induced damage probability may be larger compared to other wind loads, and **design against thunderstorm loads is necessary** (currently **not** contemplated by standards)

References

[1] Recommended lateral force requirements and commentary, 6th ed., Structural Engineers Association of California (SEAOC), Sacramento, California, (1996).
[2] A. Latto, H. Resnikoff, E. Tenebaum, The evaluation of connection coefficients of compactly supported wavelets, in: Proceedings of the French-USA workshop on Wavelets and Turbulence, Princeton University, (June 1991).
[3] T.-H. Le, L. Caracoglia, Computer-based model for the transient dynamics of a tall building during digitally simulated Andrews AFB thunderstorm, Computers and Structures 193 (2017) 44-72.
[4] W. Cui, L. Caracoglia, Simulation and analysis of intervention costs due to wind-induced damage on tall buildings, Engineering Structures 87 (2015) 183–197.

Acknowledgements

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