Wind Load Uncertainty Effects on Long-Span Bridge Aeroelasticity: from Stochastic Dynamics to Artificial Intelligence Surrogate Models

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Luca Caracoglia is an Associate Professor in the Department of Civil and Environmental Engineering of Northeastern University, Boston, Massachusetts, USA. He joined Northeastern University in 2005. Prior to this appointment, he was a post-doctoral fellow in the Department of Civil Engineering at Johns Hopkins University, Baltimore, Maryland (USA) in 2001-2002 and a post-doctoral research associate in the Department of Civil and Environmental Engineering at the University of Illinois (Urbana-Champaign, USA) in 2002-2004. He received his Ph.D. in Structural Engineering from the University of Trieste, Italy in 2001. His interests are in structural dynamics, random vibration, wind engineering, fluid-structure interaction of civil engineering structures, linear and nonlinear cable network dynamics, wind-based energy harvesting systems and wind energy. Luca Caracoglia received the NSF-CAREER Award in 2009. He was elected Fellow of the American Society of Civil Engineers in 2020.

Abstract

Long-span bridges are particularly sensitive to wind excitation. This presentation will examine the relevance of wind load uncertainty propagation and its effects on wind-induced bridge vibrations. Uncertainty can be associated with either measurement errors (for example in wind tunnel) or modeling simplifications. In the first part, reduced-order models will be employed to estimate the stationary probability distribution of a generalized variable vector, simulating the wind-induced bridge response contaminated by various error sources. In the case of serviceability and buffeting vibration, this methodology will derive the joint-probability density function of a random state vector, which includes the influence of the errors. In the case of flutter (dynamic instability of the bridge deck), stochastic bridge stability due to parametric perturbation will be evaluated. The second part will examine Monte-Carlo simulation algorithms for uncertainty quantification and to study the loss of performance in a long-span bridge, produced by wind-induced vibration. The simulation is based on the concepts of "fragility functions", used to examine the probability of exceeding pre-defined deck vibration thresholds, and the analysis of long-term maintenance costs due to structural and non-structural deck damage. Errors in the aeroelastic loads (flutter derivatives) will be considered. Finally, wind tunnel studies conducted on a single-box deck model will be discussed to quantify experimental errors and their effects on the prediction of flutter instability. In this context, the study will introduce how Artificial Intelligence can be innovatively employed to estimate bridge flutter occurrence without requiring the direct solution of the equations of motion. Application examples are derived from models of either existing or simulated bridges with variable deck spans.

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