The Investigation of Multi-Variate Random Pressure Fields Acting on a Tall Building Through Proper Orthogonal Decomposition

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Summary

The unsteady wind pressure fields deriving from the atmospheric boundary layer interacting with the aerodynamics of a tall building can be represented as spatially-correlated multi-variate random processes. Due to its random nature, the fluctuating pressure field can be considered as the superposition of a large number of independent partial pressure fields related to particular mechanisms of the excitation. It is within this context that Proper Orthogonal Decomposition (POD), a powerful statistical tool particularly suitable to deal with a large number of random variables, can be used to enhance the understanding and help with the interpretation of the physical phenomena that can drive the wind-induced dynamic response of tall buildings. The main purpose of the work presented within this technical paper, which makes use of wind pressures measured on a scaled wind tunnel model of a prismatic 180m tall building, was to identify hidden physical phenomena embedded within chaotic wind pressure fields with the idea of potentially simplify the analysis work and reduce the increasing demand for wind tunnel data storage. More specifically, this paper will show how complex fluctuating wind pressure fields – driving the response of tall buildings in both the along- and the cross-wind direction – can be approximated by a few dominant standard modes of the pressure field itself.

Keywords: POD; eigenvalues; eigenvectors; covariance; aerodynamics; wind loading.

1. Introduction

Proper Orthogonal Decomposition (POD) is a powerful statistical tool which has been developed over the course of many decades across different scientific fields (e.g. biology), often in a rather autonomous and independent way. One of the most interesting features of the different POD techniques is their ability of identifying the most energetic coherent structures behind multivariate stochastic observations. In structural engineering these techniques can be very relevant as they can assist wind engineers in gaining a much deeper understanding of the physical meaning behind the different wind loading mechanisms that can drive the structural behaviour of large roofs and / or tall and supertall buildings. Although POD has drawn the attention of wind engineers from the 1960s, it is not until the late 1990s that we see one of the first direct application of POD to the investigation of the pressure field acting on a prismatic tall building: it is in fact in this technical paper by Kikuchi et al. [1] that it is shown how the generalised along- and cross-wind forces measured in a boundary layer wind tunnel can be reconstructed by very few modes. Carassale [2], starting from the same set of measurements, subsequently employed the so-called Covariance Proper Transformation (CPT) and Spectral Proper Transformation (SPT), two decomposition techniques that respectively make use of the covariance matrix and spectral matrix which will be described in the next section of this technical paper. With particular emphasis to the realm of structural dynamics, an important boost to the application of POD techniques has been marked by the introduction of the Double Modal Transformation (DMT) in the work by Carassale et al. [3]: this method is based on the joint expansion of the Lagrangian motion coordinates, through classic modal analysis, and of the random loading process, using CPT and SPT based decompositions.

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