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A quasi-steady model to estimate the aeroelastic response of slender structures subjected to thunderstorm outflows

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DEDICATION

This work is dedicated to its conceiver, Professor Giovanni Solari. The following abstract has been written by one of the many students who had the fortune to be supervised by him in his career.

KEYWORDS: transient aeroelasticity; time-varying damping and stiffness; quasi-steady approach; downbursts; thunderstorm-induced effects on structures; structural dynamics.

ABSTRACT

Aeroelastic studies of structures are usually conducted under the applicability of the strip and quasi-steady theory. This translates into assuming a long enough time for structure and fluid to synchronize, generally in the order of several cycles of oscillations. The strip and quasi-steady theory allows a direct relationship between the wind and the pressure and/or force fields to be established, and its applicability is robust when dealing with the action of synoptic winds. These have indeed steady characteristics in both wind speed and flow direction. On the other hand, the case of transient phenomena, such as the thunderstorm outflows or downbursts, present features that strongly differ from the synoptic reference, being characterized by sudden variations of the wind speed and, often, of the flow direction as well. This last point gives rise to a couple of important questions: what does it happen in the course of a phenomenon in which the sudden change of the wind direction gives rise to rapid alternations of classically stable or unstable conditions? Is a short-term entry into an unstable domain sufficient to cause structural instability? To answer these questions, a reformulation of the whole problem of structural aeroelasticity on transient bases is needed.

The present work aims to propose a first step in this direction, and this can be made by newly invoking the quasi-steady approach. This translates into implicitly considering the passage of the gust front as sufficiently slow. The formulation is proposed for a slender body with a compact cross-section (to neglect torsional effects). Vortex-shedding phenomena is disregarded from the analyses. The motion-induced forces linked with the transversal galloping may be evaluated as:

$$\boldsymbol{f_a}(Z,t) = -\widetilde{\boldsymbol{C}}_{\boldsymbol{a}}(t)\dot{\boldsymbol{P}}(Z,t) - D\beta(t)\widetilde{\boldsymbol{K}}_{\boldsymbol{a}}(t)\boldsymbol{P}(Z,t), \quad (1)$$

where Z is the structural axis, $\widetilde{\boldsymbol{C}}_{\boldsymbol{a}}$ is the time-varying principal aerodynamic damping matrix, and $\widetilde{\boldsymbol{K}}_{\boldsymbol{a}}$ is the time-varying principal stiffness matrix. $\dot{\boldsymbol{P}}$ and $\boldsymbol{P}$ are the principal structural velocity and displacement, while $D\beta$ represents the temporal derivative of the flow direction. When comparing Eq. (1) with the classical formulation for synoptic winds, one might observe that the aerodynamic damping matrix is now a function of time, since the flow direction and the mean wind speed are not constant. Secondly, the second term was absent in the original case. From Eq. (1), three different levels of analyses for the estimate of the dynamic response of structures may descend,

according to the wind event. The most general one, Eq. (1), has to be applied for travelling downbursts. Spatially stationary downbursts are instead linked with a regular flow direction, and to study their effects the modification of the structural stiffness may be neglected. Finally, to consider a constant mean wind speed and flow direction leads to the classical formulation for synoptic winds.

The formulation has been applied to estimate the dynamic response of the Brâncuși Endless Column subjected to the effects of ten 10-minute signals linked with thunderstorm outflows, acquired from anemometric stations. These have been selected to have a dataset composed of events whose flow direction exhibit different behaviours. Indeed, 4 of them are quite regular in time, whereas the other 6 exhibit remarkable changes in that aspect. The anemometric signals are converted into compatible vertical wind fields by applying a pseudo-deterministic approach (the Equivalent Wind Spectrum Technique) on a suitable portion of the turbulent component. As far as the mean part is concerned, the model by Wood and Kwok has been adopted. The buffeting forces are subsequently evaluated by considering the directionality effects. This method is valid under the hypothesis of small turbulence, in consistency with classic aeroelastic studies.

The Brâncuși Endless Column is investigated in two of its configuration: the first one (C1) is characterized by high defence with respect to aeroelastic phenomena. The second one (C2) is the naked column and wrapped in a plastic sheet, which characterized the structure during the restoration works carried out in the Nineties. In this second case, the Scruton number is definitely lower. The structures are considered as characterized by linear elastic behavior, their natural frequencies are well-separated and the damping is small and proportional. Only the contribution of the first mode of vibration is considered in the analysis.

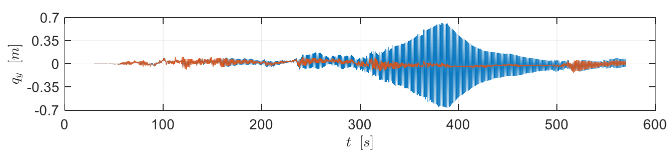

Figure 1. Crosswind response of C2 subjected to a spatially stationary downburst taking aeroelastic terms in to account (blue) and neglecting them (orange).

The results indicate that the aeroelastic terms may play a role in the dynamic response of the C2 configuration. In particular, the variation of the flow direction appears as a fundamental parameter. Indeed, when this is aligned with one incidence of the structure prone to galloping, the model predicts that the C2 crosswind response is dominated by the aeroelastic terms during the peak phase (Figure 1), before decreasing in the ramp-down. This means that a sufficient activation time has been provided to the fluid and the structure to synchronize. In the final paper, the action of 1-hour thunderstorm outflows will be taken into consideration.

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