An estimation of the unsteady lateral force on two full scale large vertical cylinders submitted to natural wind

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SUMMARY:
The paper deals with full scale measurements performed on two vertical cylinders submitted to natural wind, one chimney of 35 m with a Reynolds number around 1.1 million, and a wind turbine tower of 155 m with a Reynolds number around 5 millions. In both cases, unsteady wall pressure measurements are performed which are processed in order to obtain an estimation of the unsteady lateral force coefficient which is of great importance in the prediction models used to determine the motion amplitude due to vortex shedding in a turbulent wind.

Keywords: vortex shedding, full scale measurements, circular cylinder

1. INTRODUCTION

The goal of the paper is to report the measurements and their post-processing performed on two full scale vertical cylinders submitted to natural wind. The first one shown in Figure 1 is an experimental chimney erected at Bouin, close to the Atlantic seashore, France, in order to measure vortex shedding excitation (Manal & Hémon, 2024). Typical Reynolds number is around 1.1 million. The second cylinder presented in Figure 2 is a large wind turbine tower, named SG14, erected in the Test Centre Østerild in North Jutland, Denmark (Kurniawati *et al.*, 2024). Reynolds number is larger, around 5 millions.

This paper focuses on the synchronized unsteady wall pressure measurements around the cylinders which are analysed using the bi-orthogonal decomposition (BOD) technique (Hémon & Santi 2003). The principle of the BOD is to decompose the signal $Cp(\theta,t)$ in a series of spatial functions $\phi_i(\theta)$ named further as "topos", coupled with a series of temporal functions $\psi_i(t)$ named "chronos". The BOD can be written as

$$Cp(\theta,t) = \sum_{i=1}^{N} \alpha_i \, \phi_i(\theta) \, \psi_i(t) \quad (1)$$

where $\alpha_i{}^2$ are the eigenvalues of the spatial or the temporal covariance matrix of the signal $Cp(\theta,t)$. N is the number of terms retained for the decomposition. The azimuth angle θ is set with the wind coming at $\theta = 0°$. The idea is to determine the unsteady pressure distribution that is generating the lateral force due to the vortex shedding induced by the wind.

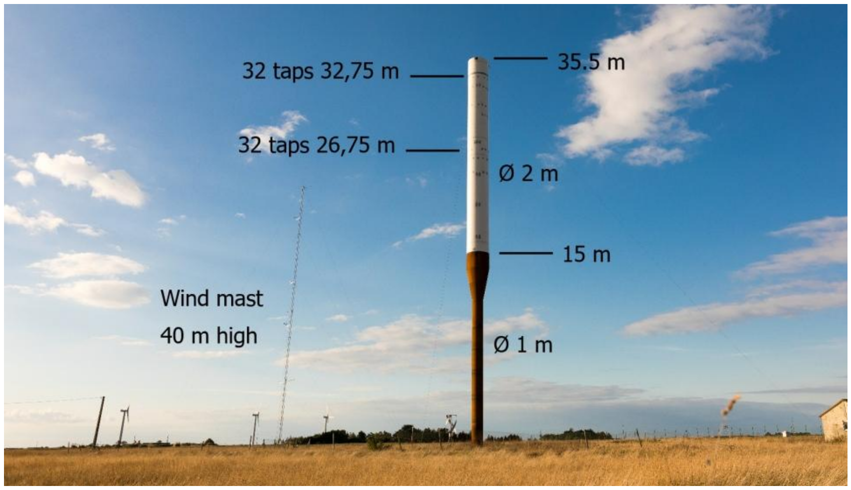

Figure 1. Photo of the Bouin chimney with its dimensions.

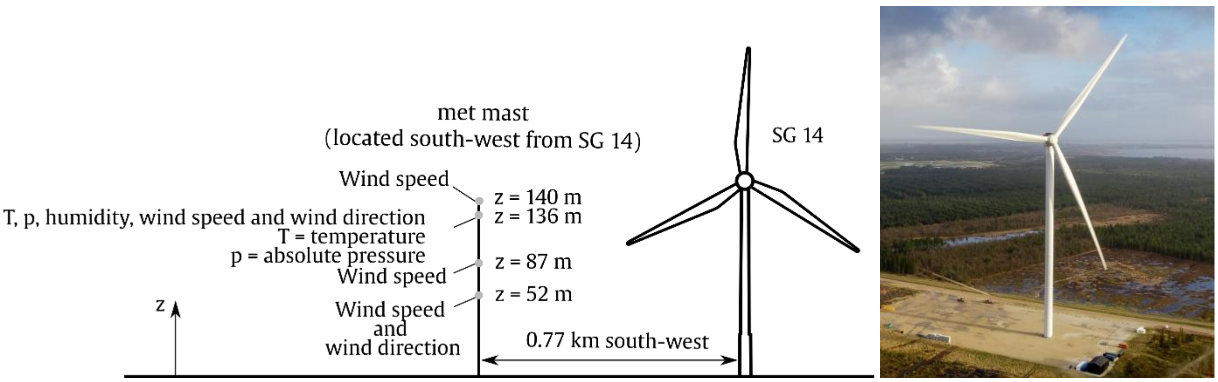

Figure 2. Sketch and picture of the wind turbine tower SG14

2. RESULTS OBTAINED WITH THE BOUIN CHIMNEY

There are 32 pressure taps mounted at the altitude 26.75 m and 32.75 m where the diameter D is 2 meters. More details on this setup can be found in (Ellingsen *et al.*, 2022; Manal & Hémon, 2024). Here we present two cases, one recorded when the chimney is at rest thanks to stay cables, and another one recorded when small oscillations occur with the maximum non dimensional amplitude $Y_{max}/D = 0.064$ at the top.
The wind characteristics are obtained thanks to a wind mast located 55 m to the west direction. They are resumed in Table 1. Thanks to the BOD, the term which is generating an unsteady lift can be identified and reconstructed in terms of an unsteady pressure coefficient Cp_u,

$$Cp_u(\theta) = \alpha_i \, \phi_i(\theta) \sqrt{\overline{\psi_i(t)^2}}. \tag{2}$$

This unsteady pressure distribution is plotted in Figure 3 and complemented by the corresponding power spectral densities. The reduced frequency is defined using the diameter D of the chimney and the mean wind speed at 26.75 m, $f_r = f\,D/U$. The first natural bending frequency of the chimney is $f = 0.848$ Hz, on which the chimney motion occurs in the second

case, leading to the peak at $f_r = 0.17$ and its harmonics.
By performing a proper integration over θ of the unsteady pressure distribution $Cp_u(\theta)$, we obtain the unsteady lateral force coefficient C_{lat} which is of great importance in the prediction of the motion amplitude. For case 1, $C_{lat} = 0.153$ at 26.75 m, $C_{lat} = 0.155$ at 32.75 m, and for case 2, $C_{lat} = 0.165$ at 26.75 m, $C_{lat} = 0.143$ at 32.75 m.

Table 1. Wind characteristics of the two selected records

Record	Data from sonic anemometer at 26.75 m					DATA from cup anemometers		
	Mean velocity m/s	Turbulence intensity %	Wind direction ° ref MN	RMS of wind direction °	Integral Scale Lu m	Mean velocity at 10 m m/s	Mean velocity at 20 m m/s	Mean velocity at 35 m m/s
1: chimney at rest	8.49	15.10	67.0	4.5	168	7.21	7.35	8.09
2: small oscillations	9.96	13.17	67.5	8.1	50	9.47	9.95	10.58

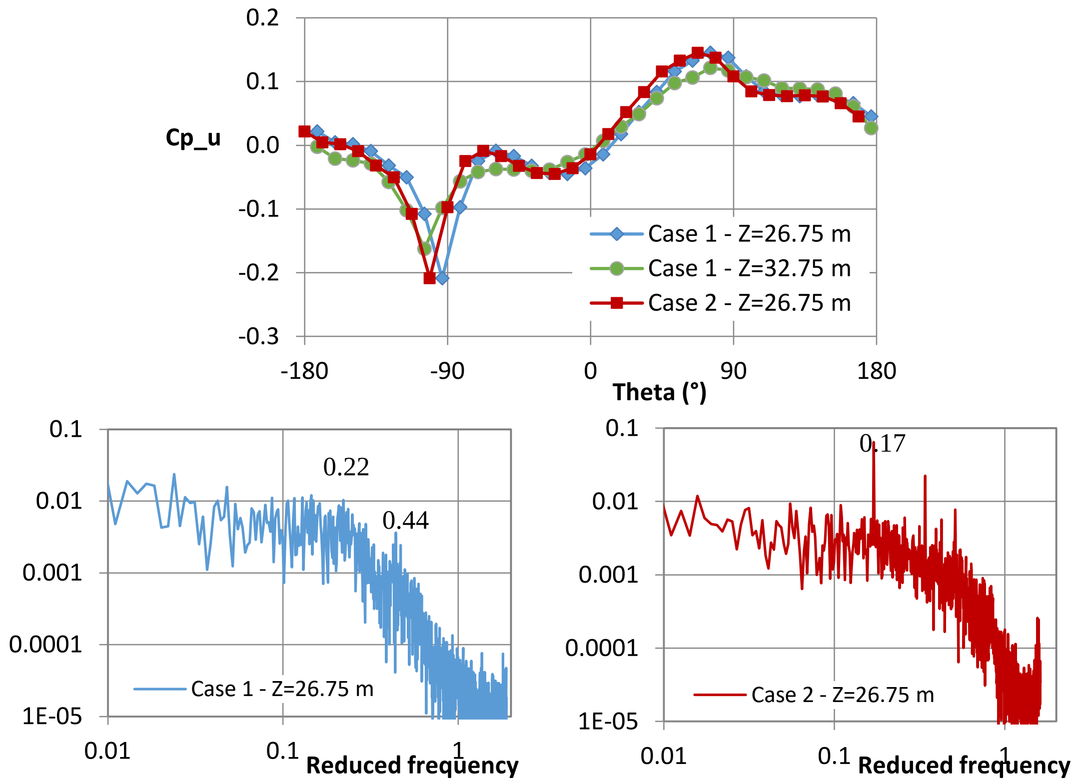

Figure 3. Unsteady pressure coefficient from term 4 of the BOD and corresponding power spectral densities.

3. RESULTS OBTAINED WITH THE TOWER SG14

The tower is equipped with two sets of 24 pressure taps at the altitude 98 and 128 m. The oscillation of the tower at the same time of the evaluated data is estimated around Y_{max}/D = 0.01 at around the tower top (149.6 m).
The same BOD technique is applied to one record of 10 minutes at 100 Hz. Once again a term generating the lift can be identified for the two sets of taps. For this 10-minute record, the wind direction comes from north-west around 290°. The resulting unsteady pressure coefficient

distribution is shown in Figure 4, with the corresponding power spectral densities.
The reduced frequency is calculated using the diameter $D = 6.5$ m and the mean wind velocities are 10.25 and 10.88 m/s for the two altitudes of measurements.
Using the pressure distribution at $z = 98$ m and $z = 128$ m respectively, the integration gives $C_{lat} = 0.148$ and $C_{lat} = 0.098$, showing in particular the effect of the top end.

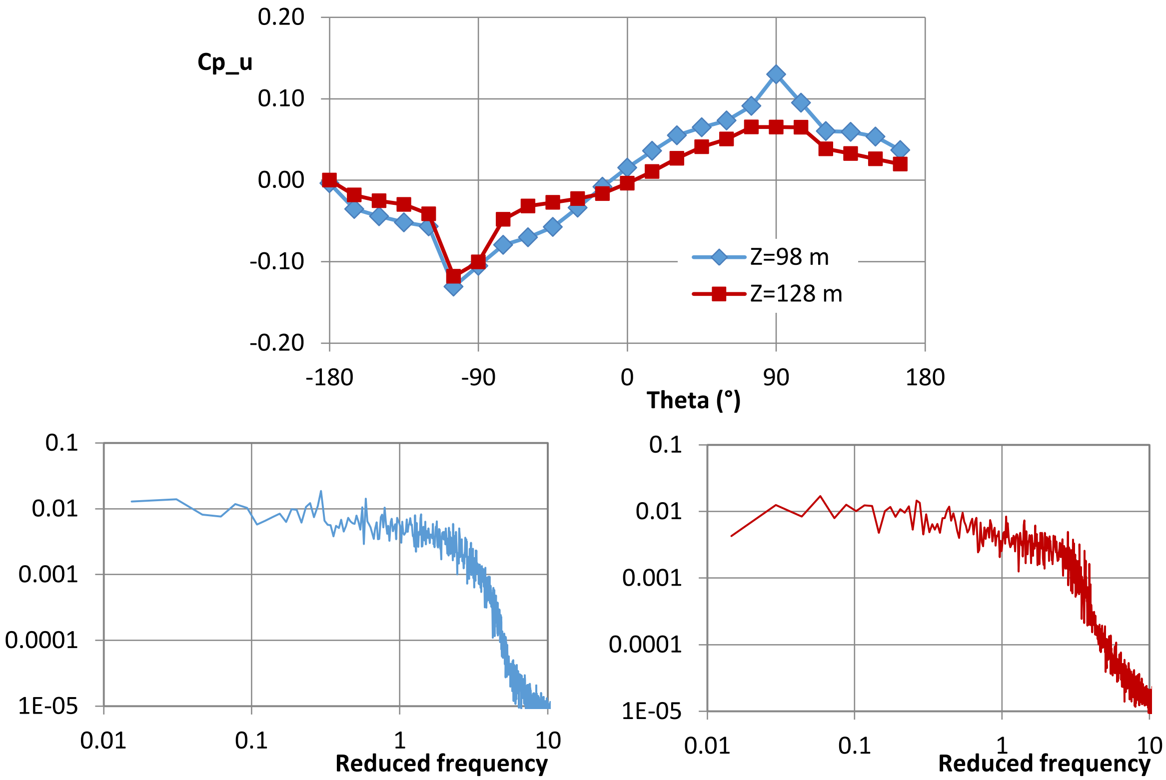

Figure 4. Unsteady pressure coefficient from term 4 of the BOD and corresponding power spectral densities.

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