

Turbulence intensity effect on the bluff bodies aerodynamic behavior

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1 INTRODUCTION

Slender high rise structures are exposed to aerodynamic problems connected to the wind-structure interaction, for example vortex shedding or dynamic instability (e.g. galloping). Generally the design of these structures requires the aid of wind tunnel tests on scaled models. The paper investigates the aerodynamic behavior of a bluff body and the shape is adopted for section of the tower of a cable-stayed bridge (Fossati et al. 2011). The problem is investigated by wind tunnel tests using a rigid sectional model with particular attention on the effects related to the turbulence intensity of the incoming flow. The present paper shows the results obtained in terms of aerodynamic forces and pressure distributions for two level of turbulence, $I_u=0.2\%$ and $I_u=2\%$. Vortex shedding phenomenon in these two conditions will be also discussed.

2 EXPERIMENTAL SET-UP

The sectional model has been realized scaling the reference section of the real bridge tower (1:18 scaled model). Figure 1 shows the section geometry that is characterized by two curved surfaces and cut edges. The distance D between the two plane sides represents the characteristic dimension of the model and it is equal to 0.446 m. The model has an aspect-ratio L/D equal to 8. It is manufactured using an internal structural beam covered by an external shell that reproduces the required geometry.

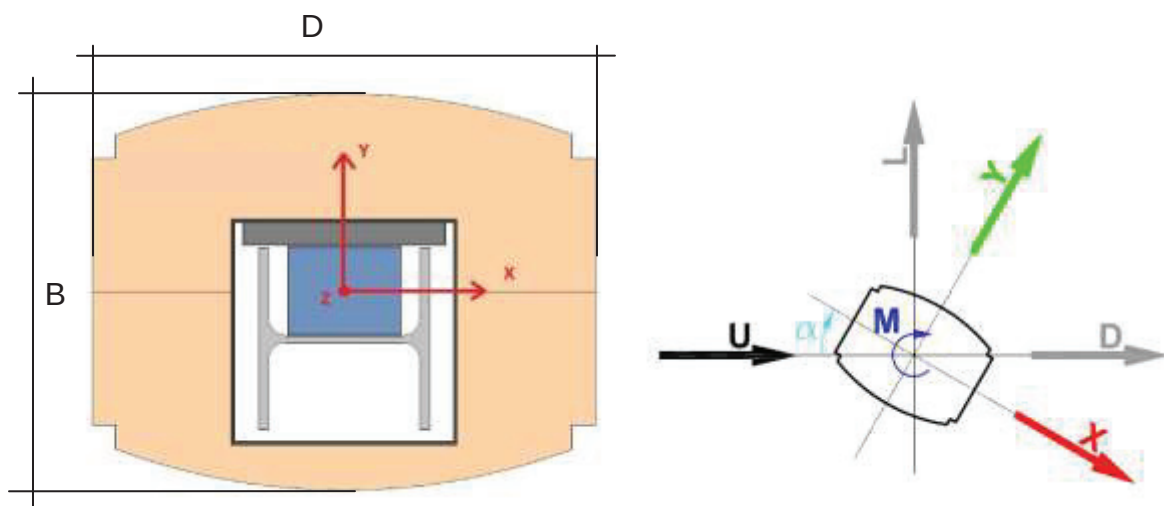


Figure 1 Section geometry: wind exposures and reference system

The external is divided in a dynamometric part, connected to the beam through a six component balance and a non-dynamometric part rigidly connected to the beam to correctly reproduce the boundary conditions for the aerodynamic forces measurements. In particular, drag

and lift forces have been considered, defined in agreement with the sketch reported in Figure 1.

Pressure taps have been placed on different sections of the non-dynamometric part in order to define surface pressure distribution. The taps were connected to high sample-rate scanners allowing high-resolution measurements of the pressure field distribution in time domain. The pressure scanners have been installed inside the model with short pneumatic connections to the pressure taps. This solution guarantees a high frequency response of the tubing system.

A total number of 96 pressure taps distributed on three different sections has been placed on the model: this configuration permit to define pressure distributions in three positions of the sectional model in order to control how the flow evolves in the axial direction. Aerodynamic forces have been obtained integrating pressure distribution along one section, and compared with the forces measured by the balance.

Experimental tests were performed in the Politecnico di Milano wind tunnel, using two different tests sections to obtain the different turbulence intensity conditions.

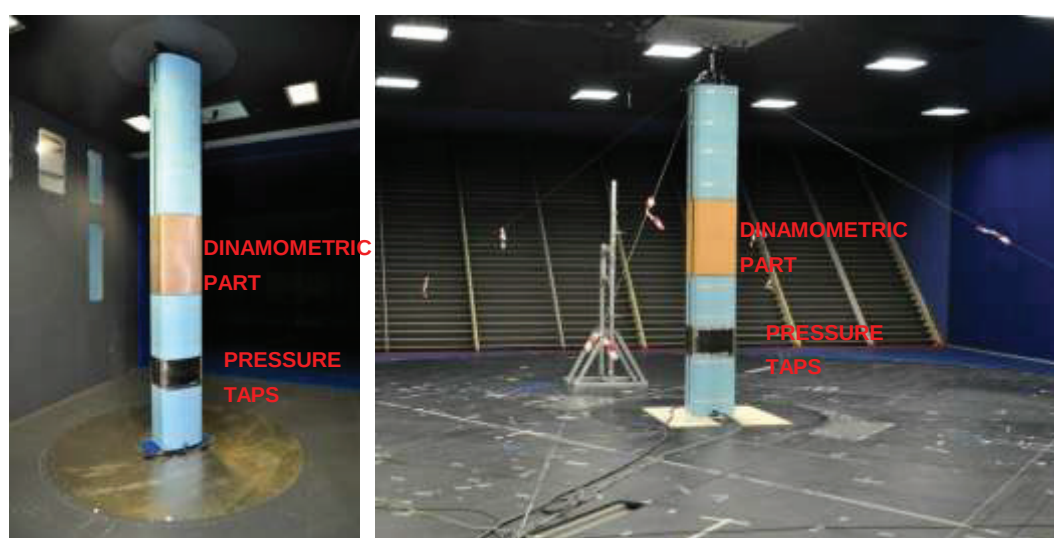


Figure 2. Wind tunnel model setup. (left) 0.2% turbulence condition (right) 2% turbulence condition

Figure 2 shows the model placed in the low turbulence tests section (left) and in the boundary layer tests section (right). Each test section is characterized by a natural value of turbulence intensity, 0.2 % and of the integral length scale $L_u^x=0.01$ m for the first one and 2 %, $L_u^x=0.2$ m for the second one. In both cases the model has been fixed on the ground obtaining a stiff structure with high structural frequencies (the lowest natural frequencies of the model are equal to 20 Hz in the low turbulence tests section and 7 Hz in the boundary layer tests section). The dynamic behavior of the model has been checked by means of two accelerometers. The model has been tested for different angles of attack as showed in Figure 1.

3 EXPERIMENTAL RESULTS

Tower sectional model has been tested for different wind exposure (0° – 90°) and for different wind velocity (up to 50 m/s in the high speed/low turbulence tests section and up to 15 m/s in the boundary layer tests section). The tests highlight that no significant dependence to the wind velocity can be observed in the tower aerodynamic behavior for the studied velocity range: for this reason the results will be presented only for one wind velocity ($V=15$ m/s, $Re=4.5 \cdot 10^5$). The forces have been obtained from the balance signals and they are in good agreement with the forces obtained integrating pressure distributions. Figure 3 shows the mean drag coefficient as a function of the wind exposure, measured both by the balance and by the pressure system.

Figure 4 compares the drag force coefficient measured in different turbulence intensity conditions as a function of the exposure angle. It is possible to notice that the aerodynamic behavior of the model is very sensitive to this parameter: a small increase in turbulence intensity completely changes the forces. In particular at $I_u=0.2\%$ the drag coefficient is quite high and it become smaller increasing the turbulence intensity. A spectral analysis of the aerodynamic forces points out that the high drag condition is characterized by a well defined vortex shedding, on the other hand the low drag condition do not highlight vortex shedding phenomenon.

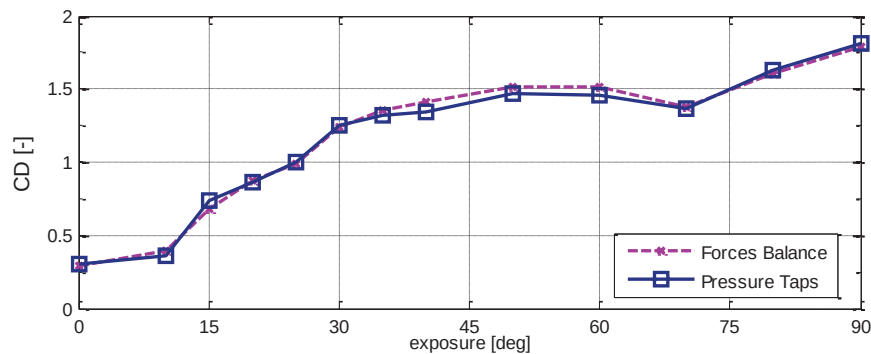


Figure 3. Comparison between drag coefficient measured by balance and pressure systems: $I_u=0.2\%$, $Re=4.5 \cdot 10^5$

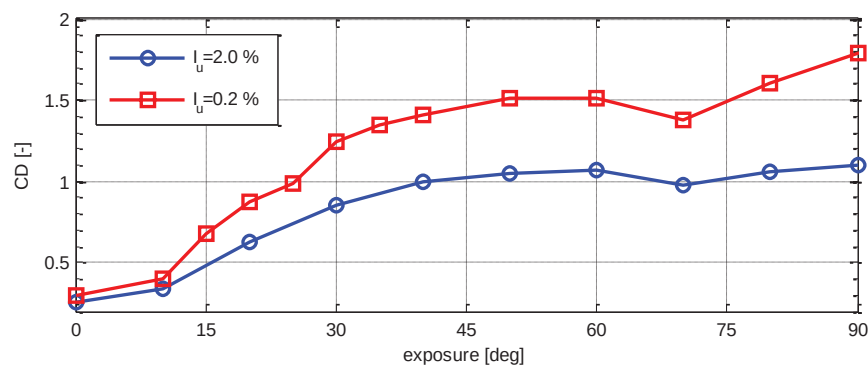


Figure 4. Drag force coefficient at $Re=4.5 \cdot 10^5$ as a function of the angle of attack and for the two tested turbulence intensity conditions

Vortex shedding is clearly identified for exposure angles higher than 20° in $I_u=2\%$ condition, while for lower angles and lower level of turbulence no significant periodic vortex shedding can be observed.

In order to better understand the phenomenon a deeper analysis has been made for each exposure angle and in particular pressure distributions and harmonic content of aerodynamic forces have been considered. In the following the results relative to 0° and 90° of angle of attack will be presented: these two cases can be considered representative of the different phenomena observed during the tests. Moreover they can also easily related to literature data concerning the aerodynamics of rectangular prisms with different aspect ratio (Holmes, 2007). In particular at 0° the tower section is characterized by an aspect ratio $B/D=1.27$, while at 90° the ratio is equal to $B/D=0.78$. Only the case at $Re=4.5 \cdot 10^5$ will be reported: similar results have been obtained also for different wind velocities. Only the pressure distributions measured along one section will be presented, others sections show similar results.

3.1 Exposure angle: 0°

The tower section at 0° does not show significant vortex shedding in both the wind turbulence conditions. Figure 5, Figure 6 and Figure 7 concern the test performed in low turbulence condition ($I_u=0.2\%$) and they report respectively the aerodynamic coefficients time histories, the

pressure distributions at four different times and the PSD of the aerodynamic coefficients. It is possible to notice that the typical narrow band related to vortex shedding phenomenon is not visible in the time histories and in the PSD of drag and lift coefficients. The absence of a periodic vortex shedding is confirmed by the pressure distributions shown in Figure 6 in terms of pressure coefficients: four different instants have been reported in order to observe how the distribution evolves in the time. The pressure distribution does not change and especially downstream large oscillations in pressure signals have not been found.

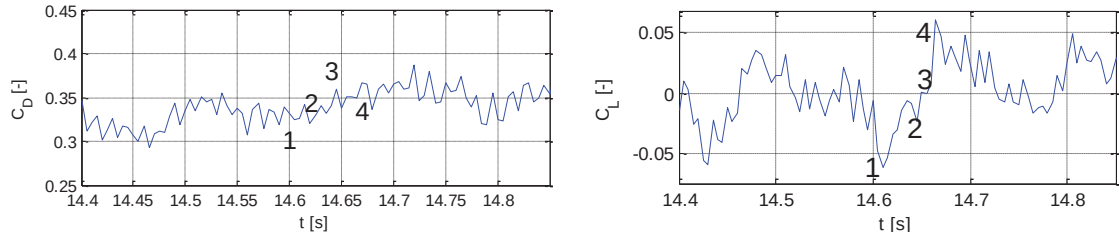


Figure 5. Drag and lift coefficients time histories zoom ($I_u=0.2\%$, $Re=4.5 \cdot 10^5$, exposure 0°)

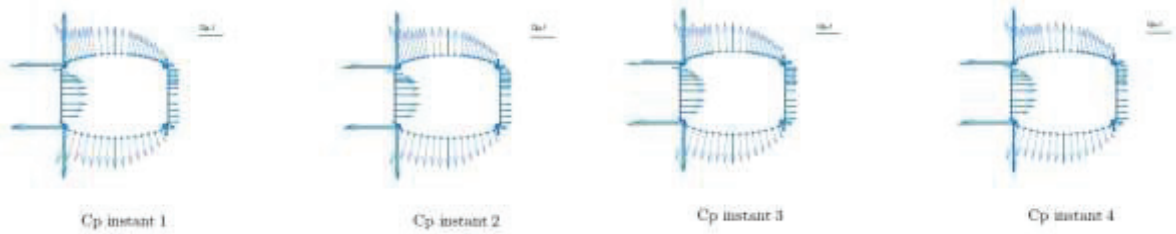


Figure 6. Instantaneous pressure coefficient on the section for the four instants identified in Figure 5 ($I_u=0.2\%$, $Re=4.5 \cdot 10^5$, exposure 0°)

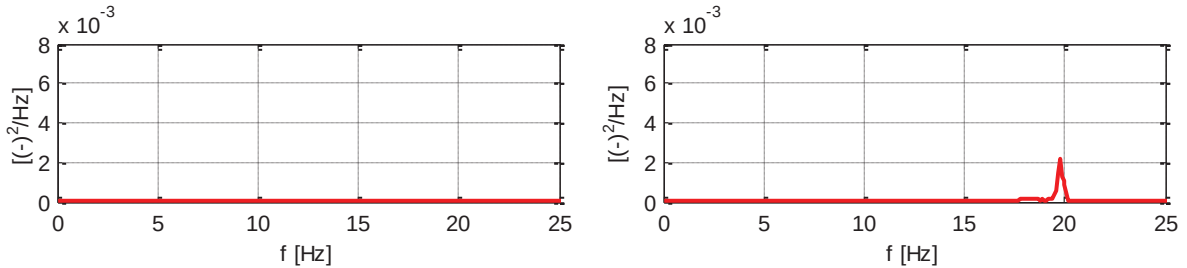


Figure 7. PSD of drag and lift coefficients ($I_u=0.2\%$, $Re=4.5 \cdot 10^5$, exposure 0°)

The tower section in higher wind turbulence condition shows a similar behavior compared to the one observed at $I_u=0.2\%$ without a clear vortex shedding. In particular the pressure distributions reported in Figure 9 are comparable with the distributions reported in Figure 6 and they do not change significantly with the time. The small peaks identified in the PSD of the aerodynamic coefficients (Figure 8) and the sinusoidal shape of the drag time history (Figure 10) can be related to a buffeting excitation in correspondence of the two first natural frequencies of the model. This excitation produces small inertial forces on the dynamometric part that were measured by the balance. These peaks are not present in the forces obtained from the pressure system and they are fixed by changing wind velocity, for these reasons they cannot be considered related to vortex shedding phenomenon.

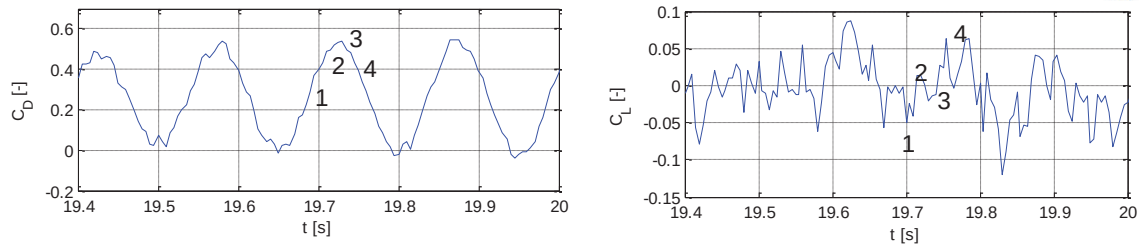


Figure 8. Drag and lift coefficients time histories zoom ($I_u=2\%$, $Re=4.5 \cdot 10^5$, exposure 0°)

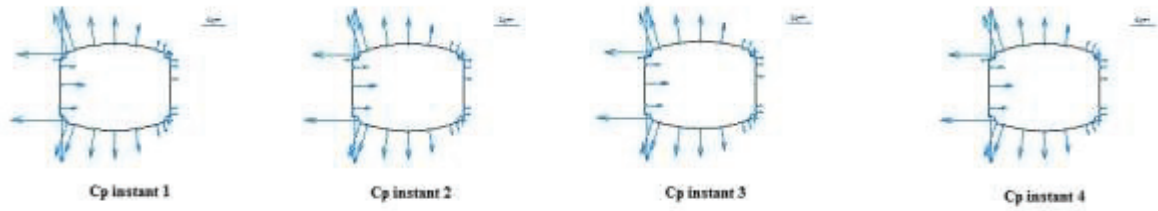


Figure 9. Instantaneous pressure coefficient on the section for the four instants identified in Figure 8 ($I_u=0.2\%$, $Re=4.5 \cdot 10^5$, exposure 0°)

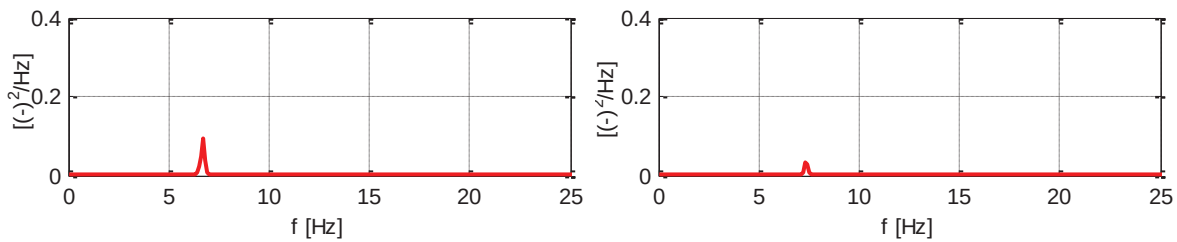


Figure 10. PSD of drag and lift coefficients ($I_u=0.2\%$, $Re=4.5 \cdot 10^5$, exposure 0°)

It is possible to note that there are small differences in the standard deviation of the pressure coefficients. The pressure coefficients have been represented as a function of the position along the section for the two wind turbulence conditions in Figure 11. In particular, the turbulence of the incoming wind increases the level of the fluctuating part of the pressures. Similar results have been found also in literature data (Nakamura & Ozono, 1987; Li & Melbourne, 1999; Albin *et al.*, 1998) considering rectangular prism: an increase in the wind turbulence move downstream the separation point reducing the wake dimension and the drag coefficient (in the presented case $C_D=0.25$ for $I_u=0.2\%$ and $C_D=0.29$ for $I_u=2\%$).

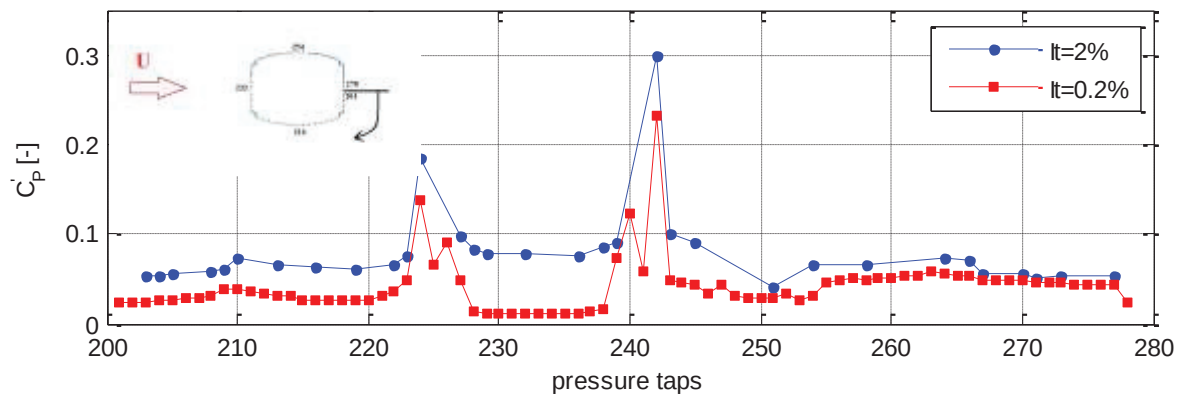


Figure 11. Pressure coefficients standard deviation $Re=4.5 \cdot 10^5$ as a function the pressure taps for the two tested turbulence intensity conditions (exposure 0°)

3.2 Exposure angle: 90°

Exposure 90° is representative of the behavior experienced by the tower with and without turbulence. The tests performed in the low turbulence test section highlight a clear vortex shedding (Figure 12, Figure 13, Figure 14) while a small increase in the wind turbulence intensity completely suppress vortex shedding (Figure 15, Figure 16, Figure 17)

In particular, in low turbulence condition the lift force coefficient is characterized by a sinusoidal trend observable both in the time history (Figure 12) and in the spectrum (Figure 14). The peak is in correspondence of a frequency equal to 5.4 Hz resulting in a Strouhal number of 0.17 and the peak moves with the velocity. Also the pressure distributions (Figure 13), relative to different points of the lift coefficient cycle, are characterized by strong oscillations: the oscillation in the pressures measured along the horizontal edges are related to the oscillation of the lift force; whereas pressures measured on the downwind curved surface change in the time due to the vortex shedding.

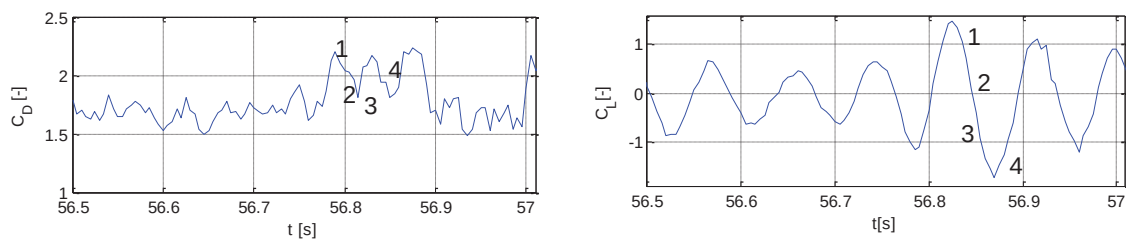


Figure 12. Drag and lift coefficients time histories zoom ($I_u=0.2\%$, $Re=4.5 \cdot 10^5$, exposure 90°)

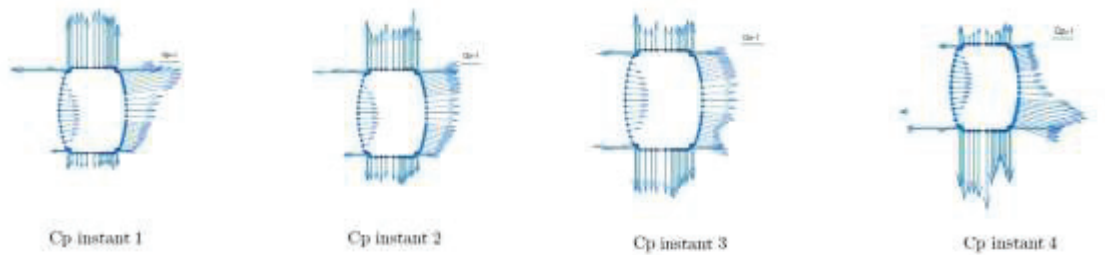


Figure 13. Ins Instantaneous pressure coefficient on the section for the four instants identified in Figure 8 ($I_u=0.2\%$, $Re=4.5 \cdot 10^5$, exposure 90°)

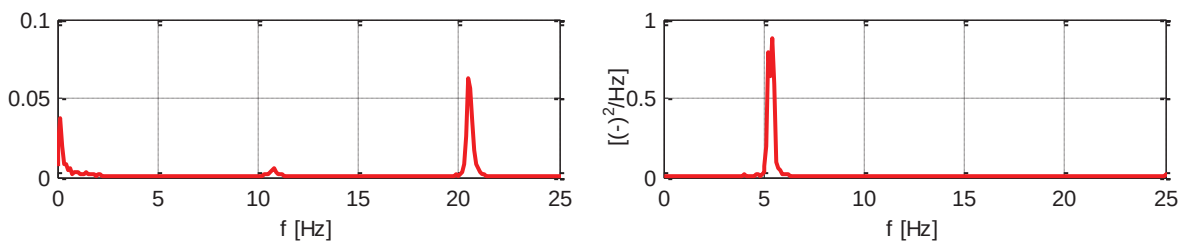


Figure 14. PSD of drag and lift coefficients ($I_u=0.2\%$, $Re=4.5 \cdot 10^5$, exposure 90°)

In the higher turbulence condition vortex shedding cannot be observed. The only oscillations observable are in drag and lift coefficients and they are referable to the forcing excitation that excites the first two natural frequencies of the model itself (Figure 15, Figure 17). In fact the pressure distributions do not highlight any vortex shedding phenomena with a constant trend with the time. The absence of vortex shedding also affects the wake dimension resulting in a lower drag compared to the one measured at $I_u=0.2\%$. However, in both the turbulence condi-

tions the mean drag coefficient is higher than the one measured at 0° : this is in agreement with the trend found for rectangular prism as a function of the aspect ratio (Holmes, 2007).

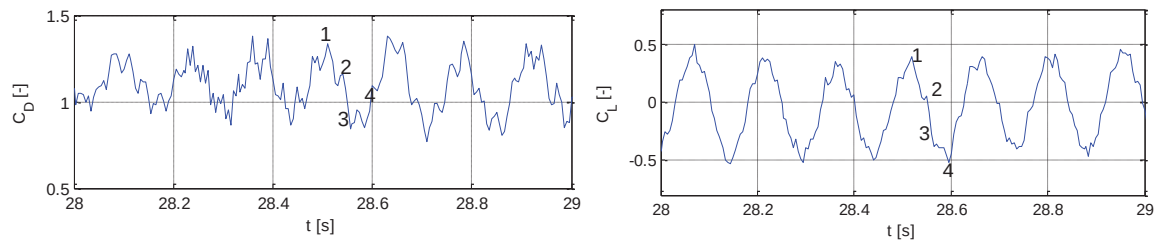


Figure 15. Drag and lift coefficients time histories zoom ($I_u=2\%$, $Re=4.5 \cdot 10^5$, exposure 90°)

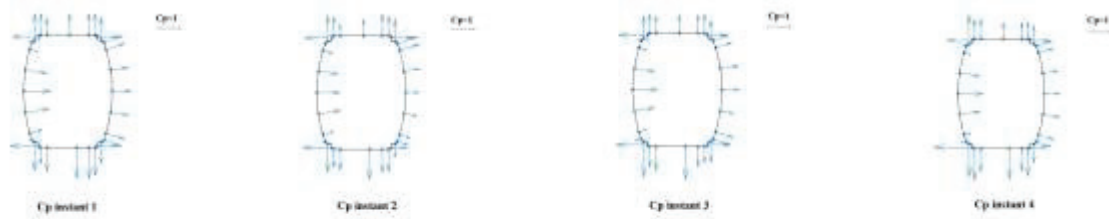


Figure 16. Instantaneous pressure coefficient on the section for the four instants identified in Figure 8 ($I_u=2\%$, $Re=4.5 \cdot 10^5$, exposure 90°)

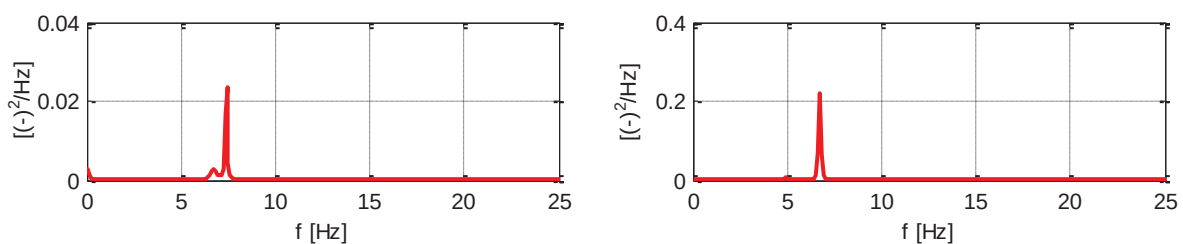


Figure 17. PSD of drag and lift coefficients ($I_u=2\%$, $Re=4.5 \cdot 10^5$, exposure 90°)

4 CONCLUSION

Traditionally studying bluff bodies, a dependence of the drag coefficient from Reynolds number is observed. During the experimental campaign performed on a section of a cable stayed bridge tower a wide wind velocity range has been investigated but no significant Reynolds number effects have been observed. On the other hand a strong dependence on the small scale turbulence of the incoming flow has been highlighted. In particular for some tested exposure angles it has been observed that a small increase in the turbulence intensity can completely suppress vortex shedding phenomenon.

Moreover it is author's opinion that not only the turbulence intensity influences the aerodynamic behavior of the model but also the length scale of the turbulence referred to the characteristic dimension of the considered section.

5 REFERENCES

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