IN-VENTO 2026
International Conference of the Italian Association for Wind Engineering
Bari, September 13th – 16th, 2026

BARI

Static wind tunnel tests on a drop-shaped cylinder for code-based design applications

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SUMMARY
This study investigates the aerodynamic properties of a sectional model of a drop-shaped cylinder for which limited aerodynamic data are available in the literature. A wind tunnel campaign consisting of static tests on sectional models with both smooth and rough surfaces was carried out to investigate the effects of angle of attack, turbulence conditions, and Reynolds number on pressure and force coefficients, also identifying the most critical angles of attack from a design perspective. Results include drag, lift, and moment coefficients, as well as frequency-domain analyses to estimate Strouhal numbers and assess vortex-induced vibration behavior and other possible aerodynamic instabilities. The findings, applied to the design of a reinforced concrete chimney using codes and guidelines, highlight significant differences compared to conventional shapes, particularly regarding vortex wake effects. These results provide a basis for a more accurate definition of wind loads and contribute to improving structural design approaches for non-standard cross-sections.

Keywords: Wind tunnel tests, Sectional model, Gust actions, Vortex Induced Vibrations, Drop Shaped Cylinders

1. INTRODUCTION

The engineering estimation of wind actions and their effects on structures is typically performed using equivalent static forces, along with checks for aeroelastic instability phenomena. Equivalent static forces are employed for structural verification under gust loading and vortex-induced vibrations (VIV), while other aeroelastic phenomena—such as galloping or torsional divergence—are addressed by demonstrating that they are unlikely to occur within the design wind velocity range.

The equivalent static load of gust actions used for standard engineering verifications is supplied as the product of the mean wind-induced static force and the gust loading factor. The latter is defined as the ratio between the mean maximum dynamic response and the mean static response. In its original formulation, assuming that turbulence is a stationary gaussian process, it was referred to the along-wind response (Davenport, 1967). Under the assumption that the structures vibrate on the first vibration mode, the formulation can be expressed in closed form (Solari, 1996), making it suitable for implementation in codes and standards (e.g., Eurocode 1, 2005; CNR, 2008). Subsequent developments enhanced these procedures through the so-called Equivalent Wind Spectrum Technique (Piccardo and Solari, 2000; CNR, 2018), providing a generalized framework applicable to along-wind, cross-wind, and torsional responses.

Vortex-induced vibrations (VIV) represent one of the most critical issues in the wind-induced response of slender structures. Code-based equivalent static forces for structural verification generally rely on two calculation procedures, namely the forced-system model and the fluidelastic system model (Païdouissis et al., 2011). The former, commonly referred to as the harmonic model, was proposed by Ruscheweyh (1994) and introduces a vortex-induced force acting over a correlation length that increases with vibration amplitude. The latter, known as the spectral model, was developed by Vickery and Basu (1983), who provided an analytical expression for an equivalent aerodynamic damping derived from a modified van der Pol oscillator. This formulation captures the inherent nonlinearity of the phenomenon and its self-limiting behavior. Other aeroelastic instability phenomena, such as galloping and torsional divergence, are typically addressed in a quasi-steady approach by demonstrating that their onset conditions are not met within the design wind velocity range.

The application of these procedures requires the definition of appropriate aerodynamic parameters, which are highly case-specific. For common cases such as circular cross-sections, these parameters are provided by design codes and documented in the literature, although significant uncertainties remain, for instance due to variability in geometric dimensions, surface roughness, flow conditions, and damping characteristics. For other types of cross-sections, the available research is far more limited, and information on the relevant aerodynamic parameters is scarce or, in many cases, nearly unavailable.

The authors were commissioned to evaluate wind actions and their effects on a reinforced concrete chimney with a drop-shaped cross-section. However, a significant lack of reliable data was encountered regarding the relevant aerodynamic parameters for this specific geometry. To address this gap, a wind tunnel testing campaign was conducted with the aim of determining aerodynamic parameters suitable for a comprehensive technical analysis. The experimental program was carried out on a sectional model of a drop-shaped cylinder, investigated through static tests. To account for Reynolds number effects and real turbulence conditions, two models with different surface characteristics, one smooth and one rough, were tested under smooth and turbulent flow.

This paper presents the sectional model and the main experimental results, with particular attention to the effects of varying the angle of attack, turbulence conditions, and Reynolds number dependence. Pressure coefficients as well as global force coefficients, including drag, lift, and moment coefficients, are provided. Furthermore, the analysis in the frequency domain allows for the evaluation of the Strouhal number and the rms lift coefficient, supporting the investigation of aeroelastic phenomena associated with vortex shedding.

Although the cross-sectional shape may appear similar to a circular cylinder, and in some respects even resemble an airfoil, comparison with the characteristic parameters of these well-known profiles reveals significant differences depending on the angle of attack, underscoring the need for careful consideration of aeroelastic effects.

2. CASE STUDY

The investigated model represents a prismatic cylinder featuring a drop-shaped cross-section (Figure 1). The model length is L=1.7 m, corresponding to the width of the wind tunnel test section, while b=60 mm is adopted as the reference dimension of the cross-section, representing its minor axis.

The model was manufactured with a carbon-fiber core and polyurethane foam. Two configurations were produced, with smooth (Figure 2 b) and rough surfaces (Figure 2 b), the latter obtained through sand-blasting followed by the application of a paint coating. The model was instrumented with pressure taps arranged along a ring at mid-span (40 taps for the rough configuration), while two force balances, one at each end, were used to measure the global forces.

The experimental campaign was conducted in the boundary layer Giovanni Solari Wind Tunnel of the University of Genoa, with test section measuring 1700×1350 mm^2 (width × height) and a length of 8.8 m. Tests on the smooth and rough surface model were performed under both smooth and turbulent flow, therefore exploring 4 different conditions The turbulent regime was generated by installing a wooden grid at the wind tunnel inlet, approximately 2 m upstream of the model, producing a longitudinal turbulence intensity of about I_u=8%. Figure 3 shows the model installed in the wind tunnel, with the internal carbon rod connected to the piezoelectric force balances, and the turbulence-generating grid. The vertical rod located downstream of the model supports the hot-wire anemometer.

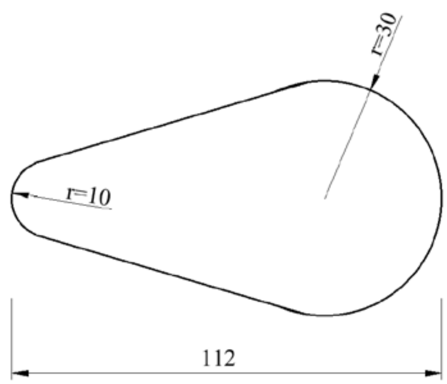
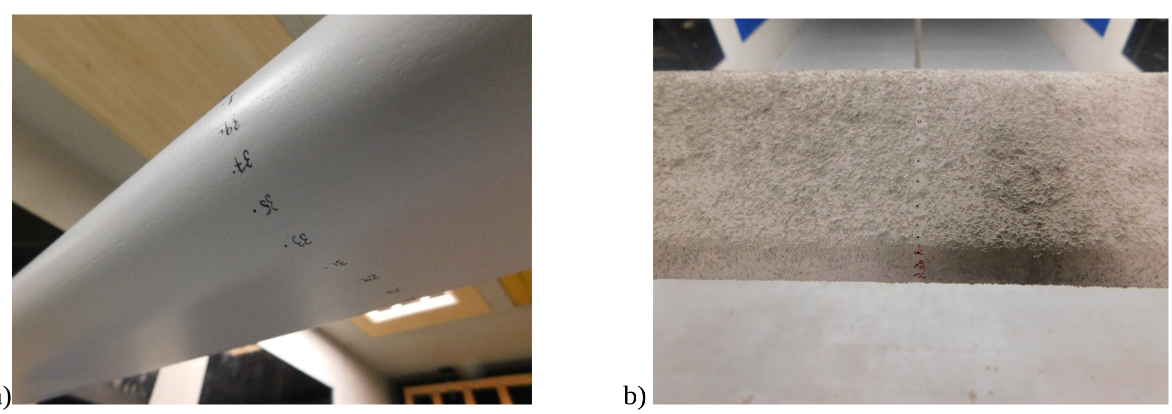


Figure 1. Model cross section, dimensions are in mm.



a) b)

Figure 2. Model with smooth (a) and rough surface (b).

Figure 3. Model in the wind tunnel

The conference presentation will showcase the results of the wind tunnel test campaign, outlining a comprehensive framework for wind load definition, with particular emphasis on the characteristics of the estimates and their implications for structural design.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the support of Società Rivieracqua (Imperia, Italy) and its Executive Director, Eng. Valerio Chiarelli.

REFERENCES

Davenport, A.G. (1967). Gust loading factors. Journal of Structural Division, ASCE, 93(3).

EN 1991-1-4 (2005). Eurocode 1: Actions on Structures – Part 1.4: General Actions – Wind Actions. CEN, European Commitee for Standardization, Brussels, Belgium.

CNR-DT 207/2008. Guide for the Assessment of Wind Actions and Effects on Structures. National Research Council of Italy.

CNR-DT 207 R1/2018. Guide for the assessment of wind actions and effects on structures. Rome, National Research Council of Italy.

Païdouissis, M.P., Price, S.J., de Langre, E., 2011. Fluid–Structure Interactions—Cross-Flow Induced Instabilities. Cambridge University Press, New York.

Piccardo, G., Solari, G. (2000). 3D wind-excited response of slender structures: Closed-form solution. Journal of Structural Engineering – ASCE 126, 936-943

Ruscheweyh, H., 1994. Vortex excited vibrations. In: Sockel, H. (Ed.), Wind-Excited Vibrations of Structures. Springer-Verlag, Wien.

Vickery, B.J., Basu, R.I. (1983). Across-wind vibrations of structures of circular cross-section. Part I: development of a mathematical model for two-dimensional conditions. Journal of Wind Engineering and Industrial Aerodynamics 12 (1), 49-74.