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# The impact of circularity defects on bridge stay cable dry galloping stability

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ABSTRACT

The present work studies the influence of circularity defects, on the aerodynamic behaviour of stay cables of cable-stayed bridges. It focuses on wind tunnel tests on High-Density Polyethylene cable covers with and without helical fillets, in a range of Reynolds numbers from the sub-critical to the critical regime. The paper considers the impact of circularity defects on the aerodynamic stability of cable sheaths by testing various amplitudes of imposed ovalization. The defects are artificially applied on real sheaths whose original cross-sections are close to circular. The experiment consists in measuring surface pressures to investigate how the amplitude of ovalization influences the flow around the sheaths, especially in the critical Reynolds number regime when transition in the boundary layer occurs. The analysis is based on bifurcation diagrams and Proper Orthogonal Decomposition. The investigation demonstrates that important circularity defects can significantly increase the bi-stable nature of the flow around a sheath at the critical regime. Nevertheless, the introduction of a helical fillet de-correlates the flow around the sheath, causing jumps in lift that have different sign along its length.

## 1. Introduction

The underlying mechanism that causes dry galloping of bridge stay cables is still under investigation by several research teams. Dry galloping causes significant vibrations of inclined cables under dry conditions, exclusively due to wind (Nikitas and Macdonald (2015)). Field observation, numerical simulation and wind tunnel tests have been used to identify the parameters that affect these vibrations. Previous studies reported that the origin of dry galloping of stay cables is related to the flow around the cable sheath at the critical flow regime (Mctavish et al. (2017), Larose and Zan (2001), Cheng et al. (2003)). These high amplitude vibrations are serious concerns for bridge safety. Most cable sheaths used in the US and Europe are either smooth or feature helical fillets, while tubes with pattern-indented surfaces are mainly used in Asia (Kleissl and Georgakis (2012)). Katsuchi et al. (2009) investigated the mechanism of dry galloping in both smooth and pattern-indented surfaces. The authors reported large cable vibrations in models with these surfaces at different Reynolds numbers. The findings exhibited the importance of the cross-section and/or the surface parameters on triggering cable vibrations near the critical regime. Furthermore, dry galloping has been proved to occur in a critical range of yaw/inclination angle and at a specific reduced wind speed (Vo et al. (2016)). In wind tunnel tests, it is possible to reproduce large cable vibrations at particular orientations. In general, the damping of the models used in such tests is low. In field observation, cable vibration amplitudes up to 1.5 m have been observed in Japan in windy and dry weather conditions (Matsumoto et al. (2010)). The estimated wind velocity was close to 18 m/s, which coincides with the beginning of the critical flow regime around these specific cables. In this flow regime, Karman vortex mitigation occurs and the drag crisis phenomenon is observed. The latter is related to the transition from laminar to turbulent flow in the boundary layers (Transition in Boundary Layer - Zdravkovich (1997)). The rapid drop in the drag coefficient is combined with the appearance of a non-negligible lift force, which is a consequence of the appearance of a negative pressure bubble on one side of the circular cylinder. Schewe (1983) used the term bi-stability to describe the occurrence of transition on either one side of a circular cylinder. Recent research conducted by Nikitas et al. (2012) and Benidir et al. (2014) showed that bi-stability causes abrupt jumps between the different regimes of the boundary layers at constant Reynolds number. However, as the dry galloping mechanism is referenced it has an aerodynamic origin; this consideration just sheds light on an important parameter, which is the macroscopic defect of the cable sheaths. The impact of the real circularity defect on flow around circular cylinders was investigated first by Flamand and Boujard (2009), then by Matteoni and

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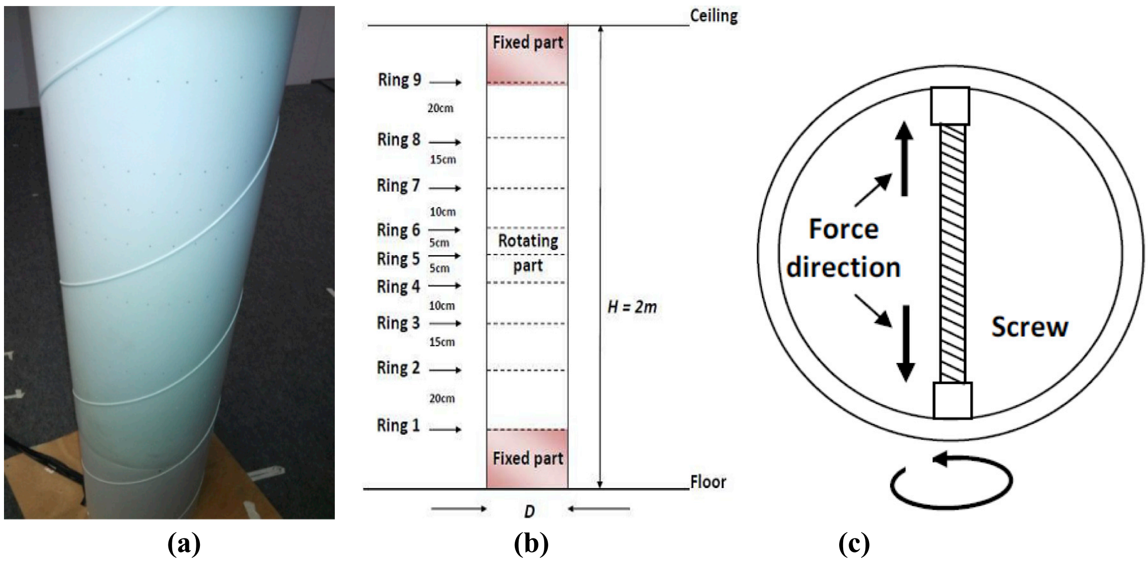


**Fig. 1.** (a) HDPE cover with helical fillets, diameter D = 250 mm; (b) 288 pressure taps (9 rings of 32 pressure taps); (c) mechanism designed for tuning the ovalization of HDPE tube.

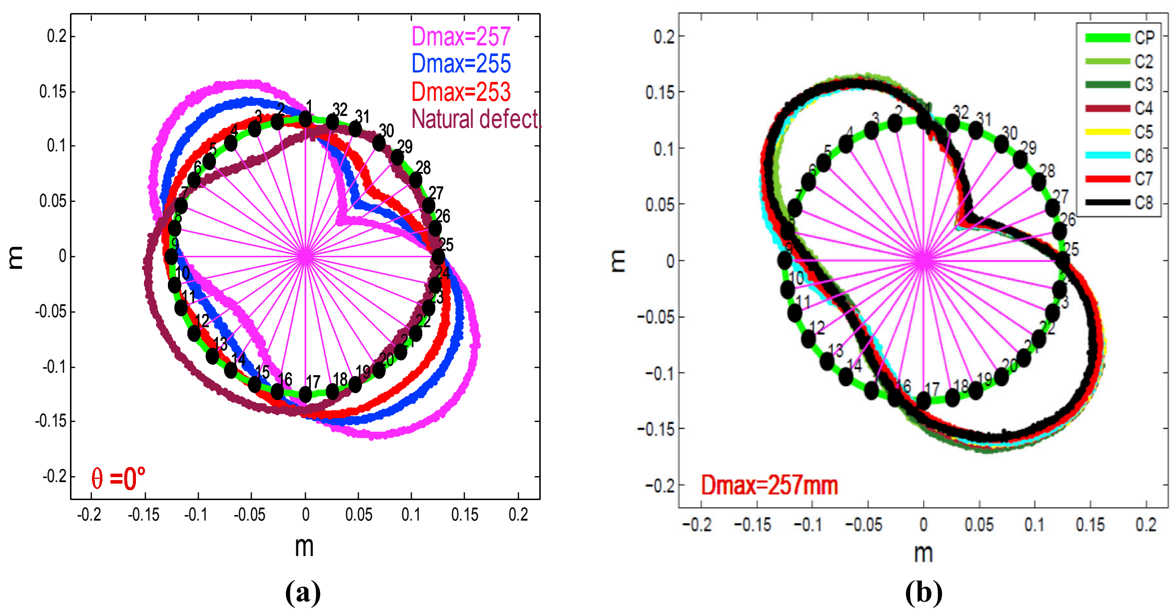


**Fig. 2.** (a) Deformations of smooth cable surfaces, (b) Circularity defect variation along the length of the cable for Dmax = 257 mm.

Georgakis (2012). Benidir et al. (2015) measured the circularity defects on four smooth High-Density Polyethylene sheaths of different diameter. They carried out wind tunnel tests to show that this defect influences the flow around the sheaths, especially at the critical regime. Ma et al. (2015) asserted that the aerodynamic forces on cables are considerably affected by the angle of attack, especially in the critical regime. Their tests were carried out on smooth cable surfaces with elliptical and semi-elliptical cross-sections.

The present work aims to investigate the impact of increasing the circularity defect of the cable sheath on the aerodynamic behaviour of stay cables by means of bifurcation diagrams and Proper Orthogonal Decomposition (POD). The paper also presents the comparison between the pressure patterns of smooth and helical fillet cable sheaths at the critical flow regime. Finally, the work investigates the impact of large deformations of the sheaths on the effect of the helical fillet.

## 2. Experiments

### 2.1. Setup

The 4 m × 2 m wind tunnel of the Scientific and Technical Centre for Building (CSTB) was used for full-scale measurements of surface pressures on cable models. Wind speed was varied from 0 to 28 m/s, corresponding to a Reynolds number range between $1.03 \times 10^5$ and $4.04 \times 10^5$. Static tests were performed on High-Density Polyethylene (HDPE) smooth and helical fillet cable covers normal or inclined to the flow with a mean diameter D = 250 mm. The results of the experiment on the smooth cables are reported in Benidir et al. (2015). A 3D surface characterization device was used to measure the surface roughness. The average roughness values (Ra) of the covers are 1.29 μm and 1.43 μm, respectively for smooth sheaths and for sheaths with helical fillet surfaces. The turbulence intensity of the wind tunnel was measured by a