ICWE 16
August 27-31, 2023
FLORENCE - ITALY
16th International Conference on Wind Engineering

Effect of cable-surface geometry on the aerodynamic behaviour of stay cables under dry-wind and ice-wind conditions

Annick D'Auteuil [1], Sean McTavish [1], Arash Raeesi [1], Krzysztof Szilder [1]

[1]National Research Council Canada, Ottawa, Canada, Annick.DAuteuil@nrc-cnrc.gc.ca

SUMMARY:
Cable-surface geometries are used to mitigate the wind-induced vibrations of stay cables of bridges. Wind-tunnel investigations were conducted on stay-cable models at the 2 m x 3 m Wind Tunnel of the National Research Council Canada (NRC). The purpose of the investigation was to evaluate the impact of using a helical fillet or concentric rings on the aerodynamic forces experienced under dry-wind conditions and under ice-wind conditions as compared to the aerodynamic behaviour of a bare-surface cable. The helical fillet has been introduced in bridge engineering to counteract rain-wind vibrations while concentric rings have been developed to address the issue with ice-wind vibrations and ice detachment from stay cables. This study aims to evaluate the aerodynamic behaviour of the cable-surface geometries under different weather conditions for which they were initially developed. The experiment investigated how the cable-surface geometry influences the maximum drag coefficient and the variation of the drag- and lift-force coefficients with Reynolds number (Re) and with wind yaw angle.

Keywords: cable surface geometry, ice accretion, aerodynamics

1. INTRODUCTION

Since the early 1990s, stay cables of bridges have been covered by a cable sheath, generally made of high density polyethylene (HDPE), to protect the bundle of steel cables from corrosion and to reduce the aerodynamic drag coefficient. However, the introduction of this smooth HDPE sheath increased the sensitivity of the stay cable to wind-induced vibrations under dry-wind, rain-wind and ice-wind conditions. Cable-surface geometries have been used to mitigate this problem. For example, the helical fillet was introduced in the late 1990s to counteract rain-wind vibrations (Larose and D'Auteuil, 2014). In the last decade, other emerging cable surface geometries were developed (Kleissl and Georgakis, 2012) mostly to counteract ice accretion problems on the stay cables. Concentric rings have been used to reduce the size of ice fragments that could detach and fall from the stays. Cable-surface geometries affect the aerodynamics of stay cables differently under various weather conditions (McTavish et al, 2020, McTavish et al, 2021). Design drag-force-coefficient values of 0.7 under dry-wind conditions and 1.0 under ice-wind conditions are commonly used in practice and are based on experience and on the *Post-Tensioning Institute (PTI): Recommendations for Stay-Cable Design, Testing and Installation* (PTI, 2018). However, cable-surface geometries might increase the drag-force coefficient at high Reynolds number under dry-wind or ice-wind conditions and an underestimation of the design value could lead to engineering issues. Experimental studies were carried out in a wind tunnel to evaluate the effect of two cable-surface geometries, the helical fillet and concentric rings, on the aerodynamic behaviour of stay cables under dry-wind conditions and under ice-wind conditions. The paper describes the experimental conditions and presents the results with the drag- and lift-force coefficients and their variation with Reynolds number and with wind yaw angle.

2. EXPERIMENTAL CONDITIONS

Seven cable models were tested. All three cable-surface geometries (bare surface, helical fillet, concentric rings) were evaluated without ice and with ice accretion, plus an extra cable with helical fillet that had a thicker ice accretion (see Figure 1). The helical fillet and concentric rings had a rectangular cross-section with the same dimensions (1 mm wide x 3 mm high). The NRC morphogenetic model (Szilder, 2018) was used to predict realistic ice accretion shapes that form on stay cables after being exposed to 2.5 mm of freezing rain conditions forming a thin layer of ice covering 2/3 of the circumference of the cable (see left side of Figure 2). An additional case was predicted for 60 mm of freezing rain, providing thicker ice accretion. All cable models were fabricated using Selective Laser Sintering (SLS) and were sanded and painted to obtain a surface roughness similar to an HDPE cable. The outer diameter of the cable models was 96 mm and the cable length was 1.5 m. The tests were carried out in the NRC 2 m x 3 m wind tunnel for a cable inclination angle (θ) of 60^o from the horizontal (see middle of Figure 2) and with the cable mounted on synchronized floor and roof turntables for yaw rotation. The models were instrumented with internal balances to measure the along-wind (drag) and across-wind (lift) forces perpendicular to the model axis. The right side of Figure 2 illustrates a schematic of the cable-wind relative orientation. A yaw angle of 0^o is defined with the main axis of the cable being aligned with the flow. A negative yaw angle corresponds to a counterclockwise rotation of the turntable when viewed from above. Aerodynamic forces acting on the static cable models were measured for Reynolds numbers from 0.4×10^5 to 5.3×10^5 and for yaw angles of 0^o, -30^o, -60^o, -90^o, -120^o, -135^o, -150^o and, under smooth flow conditions (0.14% longitudinal turbulence intensity).

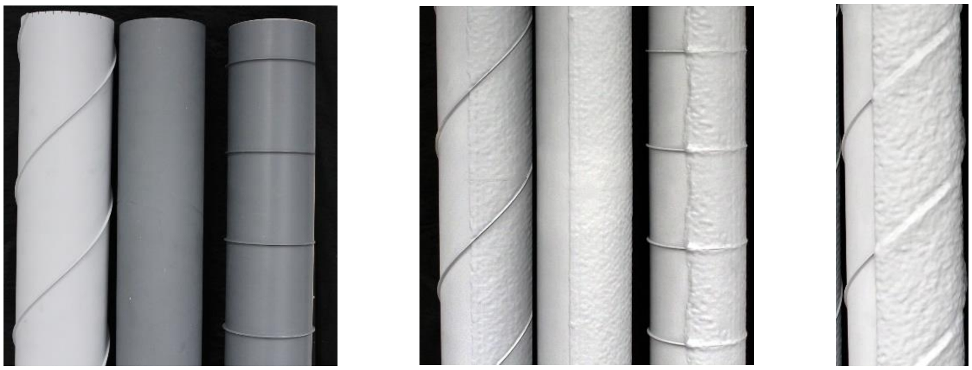

Figure 1. Left: cable models for dry-wind conditions with helical fillet, bare surface and concentric rings. Middle: cable models with thin simulated ice, Right: cable model with thick simulated ice.

3. RESULTS

The results of the aerodynamic force coefficients for the cables with helical fillet and with concentric rings are presented in Figure 3. The results for cables without ice (dry) and for thick ice are presented only for yaw angles that have shown extreme minimum or maximum values for the range of yaw angles covered in this study. The results indicated that under dry-wind conditions, the maximum C_D at high Re ($5\text{x}10^5$) was 0.76 for the cable with helical fillet and was 0.58 for the cable with concentric rings, both for a yaw angle of -90°. With thin ice accretion, the maximum C_D increased slightly to a value of 0.8 (by 5%) for the cable with helical fillet at -90° and to 0.65 (by 12%) at -120° for the cable with concentric rings. The results indicated that for cables with a smooth surface roughness (similar to new HDPE) and under smooth flow conditions, the common C_D design value (1.0) is conservative for stay cables using concentric rings under dry-wind conditions and under thin ice-wind conditions. However, for the cable with helical fillet, a design value of 0.8 would be more conservative under dry-wind conditions to cover the aerodynamic behaviour observed in this study. On the other hand, even with thick ice accretion formed after a 60 mm freezing rain event, the maximum C_D observed for a cable model with helical fillet was below the common design C_D value of 1.0. It is expected that higher C_D value would be obtained for a cable with a rougher surface (dust or particles accumulated on the HDPE cable after years of service) and/or for higher wind turbulence and/or for ice accretion that forms at lower ambient temperature creating a large asymmetric cable-ice shape. The results of the lift coefficient, C_L, indicated potential instability of the cable with a bare surface (results not shown here) and with a helical fillet. A large variation of C_L with Re and with yaw angle was observed under dry-wind and to a lesser extent under ice-wind conditions. However, the cable with concentric rings has shown a stable behaviour with a lift force with a near-zero value across the Re range and wind yaw angles covered in this study and under dry-wind conditions.

Figure 2. Left: cross-sectional view of the cable with the ice covering the circumference shown in dark green, Middle: Close-up view of one cable model installed in the wind tunnel, Right: Schematic of cable-wind orientation.

4. CONCLUSION

This extended abstract has described wind-tunnel experiments to evaluate the aerodynamic force coefficients for cable models with a bare surface, with a helical fillet and with concentric rings, under dry-wind and ice-wind conditions. The cable models were painted to represent a surface roughness similar to new HDPE cables and tests were completed under smooth flow conditions. The maximum drag coefficient at high Reynolds number observed under the current study revealed that the design C_D value used in common practice is conservative for a cable with concentric rings but should be higher than 0.7 for cables with helical fillet under dry-wind conditions. The cable with concentric rings has shown a stable behaviour to across-wind motion with a near-zero value of lift force coefficient under dry-wind conditions for the range of Re and yaw angles covered in this study while cables with bare surface or with helical fillets have shown significant variation of C_L with Re and with yaw angle leading to potential cable instability.

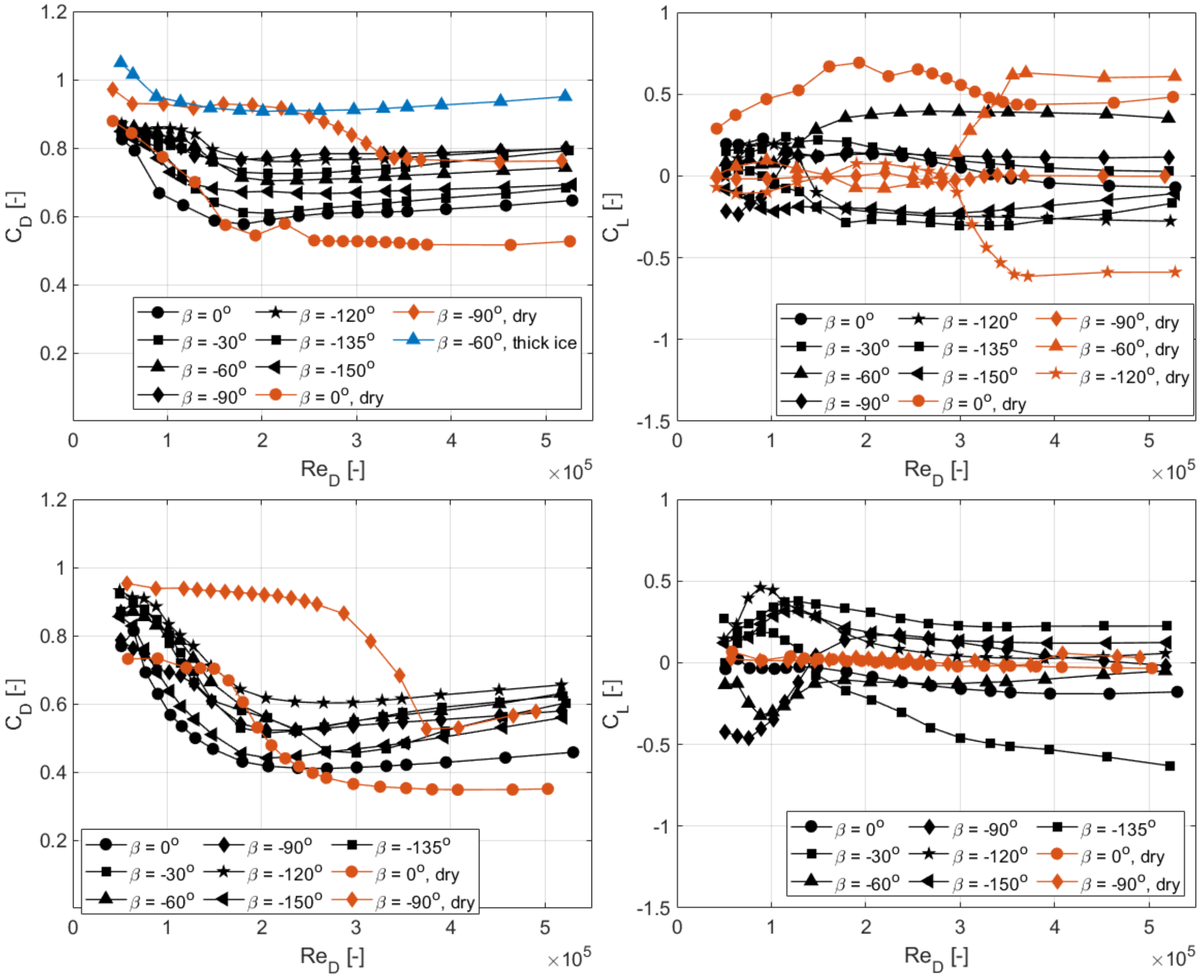

Figure 3. Variation of the drag and lift force coefficents with Reynolds number for different wind yaw angles β for cables with thin ice (black lines), with thick ice (blue line) and for cables without ice (orange lines). Top: Helical fillet, Bottom: Concentric rings.

ACKNOWLEDGEMENTS

The authors acknowledge the financial support of Infrastructure Canada through the Climate-Resilient Buildings and Core Public Infrastructure Project and the Climate Resilient Built Environment Project.

REFERENCES

McTavish, S. et al. (2020), “Effect of cable surface characteristics and flow turbulence on the aerodynamic behaviour of stay cables in dry conditions,” Journal of Wind Engineering and Industrial Aerodynamics, **207**.

McTavish, S. et al. (2021), “Effect of cable surface geometry and ice accretion shapes on the aerodynamic behaviour of inclined stay cables,” Journal of Wind Engineering and Industrial Aerodynamics, **216**.

Kleissl, K. and Georgakis, C. (2012), “Comparison of the aerodynamics of bridge cables with helical fillets and a pattern-indented surface,” Journal of Wind Engineering and Industrial Aerodynamics, **104-106**, pp. 166–175.

Larose, G. L. and D’Auteuil, A. (2014), “Wind Tunnel Investigations of an Inclined Stay Cable with a Helical Fillet,” No. FHWA-HRT-14-070, Federal Highway Administration.

PTI Guide Specification (2018), “Recommendations for stay cable design, testing and installation DC45.1-18, 7th edition”, Post-Tensioning Institute Committee on Cable-Stayed Bridges.

Szilder, K. (2018), “Theoretical and experimental study of ice accretion due to freezing rain on an inclined cylinder,” Cold Regions Science and Technology, **150**, pp. 25–34.